WATER DEMAND OF SELECTED RESIDENTIAL PROPERTIES WITH ACCESS TO GROUNDWATER IN SERVICED AREAS OF THE CAPE PENINSULA

by

Tiaan Wright

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Supervisor: Prof HE Jacobs

Department of Civil Engineering

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This thesis is dedicated to my soul mate, Ahnel, and our first born son, Joshua.

May I realise each day how blessed I am with you in my life.

I love you with all my heart!

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: March 2013

Abstract

This study focuses on the water demand of selected residential properties with access to groundwater in serviced areas of the Cape Peninsula. This winter rainfall region is typified by hot and dry summer months, corresponding to peak garden water demand. Water restrictions in the area are relatively common and primarily target outdoor use. Groundwater serves as an alternative source of water to some consumers in the area, but little is known about the extent of such use and the impact thereof on potable water demand.

A major part of the area is underlain by a primary, unconfined aquifer that has been reported to have high exploitation potential. Its unconsolidated sand and shallow water table provides ideal conditions for small scale groundwater abstraction. Several owners of properties situated above the aquifer unit have capitalised on this and utilise groundwater as an alternative to potable water, mostly for garden irrigation purposes.

The main objective of this research was to investigate the average extent of the expected reduction in average annual municipal water demand due to private groundwater use at the selected properties in the study area. The methodology involved abstracting data from the City of Cape Town's registration process for the private use of non-potable water. The data was recorded between 2000 and 2006 and was available only in hard copy format.

The registration data was used to identify residential properties with access to private groundwater sources, based on the physical addresses recorded on the registration forms. The rate of groundwater abstraction was not recorded during the registration process, nor was any of the properties spatially referenced. The data set contained information for 4 487 properties, of which 3 764 could ultimately be used in the analysis.

Data from a recent hydro-census in Hermanus (which was done by others prior to this study) was used to test the intended research method first. This trial investigation involved only 114 properties and was used to streamline the proposed methodology for application on the full-scale analysis of the City of Cape Town data.

Each address was captured electronically, verified manually and filtered to extract only those representing residential properties for which groundwater use was registered. In order to identify the properties spatially, the addresses had to be converted to coordinates through a procedure called geocoding, so as to plot each spatially and obtain the attributes such as stand size, position and the unique Surveyor General's code. This was necessary in order to link the addresses to the municipal treasury system and obtain their latest available water consumption records using a commercial software package that incorporates consumer information.

Next the actual annual water consumption figures were compared with recently published water demand guidelines based on stand size as single explanatory variable. The selected residential stands were divided into pre-defined stand size categories. The average water consumption of all the stands in each size category was calculated and compared with the suggested water demand as per the guidelines used, based on the centre value of the size range of each category.

The results of the comparative analysis confirm findings from two earlier studies where lower municipal water use was reported for residential properties with access to groundwater in a summer rainfall region. The results further showed that the mean average annual potable water demand of consumers in the study area with access to groundwater was on average 31.4% lower than those considered without such access in the same region. This represents an average reduction of 333 l/stand/day (about 10 kl/stand/month) in the potable water demand of the selected residential stands.

This study therefore confirms that serviced residential stands with access to private groundwater sources in the Cape Peninsula have lower average metered water consumption from the municipal supply system.

Opsomming

Hierdie studie fokus op die water anvraag van geselekteerde residensiële erwe met toegang tot grondwater in gedienste woongebiede van die Kaapse Skiereiland. Die gebied is 'n winterreënvalstreek, met warm, droë somermaande wat saamval met piek water aanvraag vir tuinbou. Waterbeperkings in die area is relatief algemeen, veral op die buitegebruik van water. Grondwater dien as alternatiewe bron vir sommige verbruikers, maar kennis oor die omvang van sulke gebruik, sowel as die impak wat dit het op die aanvraag na drinkbare water is beperk.

Die grootste deel van die gebied ter sprake is geleë bo 'n onbegrensde hoof waterdraer, met berigte hoë ontginningspotensiaal. Die ongekonsolideerde sand en hoë watertafel is ideal vir kleinskaalse grondwateronttrekking. Heelwat van die eienaars van grond wat bo hierdie akwafeer geleë is het die situasie uitgebuit en gebruik grondwater as alternatief vir drinkwater, veral vir tuinbesproeiïng.

Die hoofdoel van hierdie navorsing was om die gemiddelde omvang van die verwagte vermindering in gemiddelde jaarlikse munisipale wateraanvraag weens die privaat gebruik van grondwater by die geselekteerde erwe in die studiegebied te ondersoek. Die metodiek het die onttrekking van data uit die Stad Kaapstad se registrasieproses vir die privaat gebruik van nie-drinkbare water behels. Hierdie data, wat tussen 2000 en 2006 vasgelê is, was slegs in harde kopie formaat beskikbaar.

Die registrasie data is gebruik om woonerwe te identifiseer met toegang tot privaat grondwater bronne, volgens die fisiese adres verskaf op die registrasie vorms. Die tempo van grondwater onttrekking was nie opgeneem gedurende die registrasie proses nie, so ook nie ruimtelike aanwysings na die ligging van die eiendomme nie. Die datastel het inligting bevat oor 4 487 eiendomme, waarvan 3 764 uiteindelik bruikbaar was in die analise.

Data van 'n onlangse hidro-sensus in Hermanus (wat deur ander gedoen is voor die aanvang van hierdie studie) is gebruik om die beoogde navorsingsmetodiek eers te toets. Die toetsondersoek het slegs 114 eiendomme behels, en is gebruik om die

voorgestelde metodologie meer vaartbelyn te maak voor toepassing op die volskaalse analise van die Stad Kaapstad data.

Elke adres is elektronies vasgevang, met die hand geverifiëer, en dan gefilter om slegs die residensiele eiendomme waarvoor grondwater gebruik geregistreer is, te behou. Om die ruimtelike verwysing van die eiendomme verder te kon indentifiseer, moes die adresse omskep word in koördinate om sodoende die erwe te kon posisioneer en die erfgrootte, posisie en die unieke Landmeter Generaal kode van elke erf te verkry. Dit was nodig sodat die adresse aan die munisipale stelsel gekoppel kon word om sodoende die jongste beskikbare waterverbruik rekords te verkry deur gebruik te maak van ‘n kommersiële sagteware pakket wat verbruikers-inligting inkorporeer.

Hierna is die werklike jaarlikse waterverbruik syfers vergelyk met onlangs gepubliseerde wateraanvraag riglyne, gebaseer op erfgrootte as enkel verklarende veranderlike. Die geselekteerde woonerwe is toe in voorafgekose kategorië verdeel volgens erfgrootte. Die gemiddelde waterverbruik van al die erwe binne elke grootte-kategorie is bereken en vergelyk met die voorgestelde wateraanvraag volgens die riglyne, gebaseer op die middelpuntwaarde van die grootte strekking van elke kategorie.

Die resultate van die vergelykende analise staaf die bevindinge van twee vroeër studies wat laer munisipale watervebruik rapporteer vir residensiële eiendomme met toegang tot grondwater in ‘n somerreënvalgebied. Die resultate wys ook dat die gemiddelde jaarlikse drinkbare water aanvraag van verbruikers in die studiegebied wie toegang het tot grondwater, gemiddeld 31.4% laer is as dit van verbruikers wie beskou word sonder sulke toegang in dieselfde streek. Dit verteenwoordig ‘n gemiddelde vermindering van 333 l/erf/dag (rondom 10 kl/erf/maand) in die aanvraag na drinkbare water van die geselekteerde woonerwe.

Hierdie studie bevestig dus dat gedienste residensiële erwe met toegang tot privaat grondwater bronne in die Kaapse Skiereiland laer gemiddelde gemeette waterverbruik vanuit die munisipale toevoerstelsel het.

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Abbreviations, Acronyms and Symbols

Technical work requires information to be conveyed accurately. Due to the precision that this requires, certain terms referred to frequently have to be reported the same each time they are used. Some terms are long and cumbersome, and to facilitate reading, these terms are defined here for constant use throughout the thesis.

&	and
=	equals
<	less than
>	more than
±	plus-minus (more or less)
%	symbol used to indicate percentage
.dbf	extension for a file in “data basis file” format
.xls	extension for a file in Microsoft Excel format
a	annum (one year i.e. 12 consecutive months)
ave	average
AADD(s)	Average Annual Daily (water) Demand(s)
API	Application Programming Interface
ASCE	American Society of Civil Engineers
BEng	Degree Bachelor of Engineering
c/o	corner of
CCT	City of Cape Town
CES	Community Engineering Services
CFAU	Cape Flats Aquifer Unit
CG	Council of Geoscience
CMA	Cape Metropolitan Area
CSIR	Council of Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
d	day

DANAF	Departments of the Army, the Navy and the Air Force (United States of America)
DWAF	Department of Water Affairs and Forestry
e.g.	for example
ESRI	Environmental Systems Research Institute
Fe	symbol for the element iron (ferrous iron)
GAP(s)	Groundwater abstraction point(s)
GEOSS	Geohydrological and Spatial Solutions International (Pty) Ltd
GHA	Greater Hermanus Area
GIS	Geographic Information System
GLS	Geustyn Loubser Streicher (Consulting)
GPS	Global Positioning System
GVR	General Valuation Roll
h	hour
H	symbol for the element hydrogen
i.e.	that is
IMESA	Institute of Municipal Engineering of Southern Africa
IMQS	Infrastructure Management Query Station
IWRP	Integrated Water Resource Planning
IWA	International Water Association
kl	kilolitre (1 000 litres or cubic meter)
kl/d	kilolitre per day
kl/stand/month	kilolitre per stand per month
km	kilometre (1 000 metres)
km^2	square kilometres (surface area)
km^3	cubic kilometre (1 000 000 000 litres)
kW	kilowatt (measure of power)
l (ℓ)	litre (volume)
l/d	litre per day

l/h	litre per hour (flow rate)
l/s	litre per second (flow rate)
l/stand/day	litre per stand per day
m	meter (distance)
m^2	square metres (surface area)
m^3	cubic meter(1 000 litres or kilolitre)
M	Mega (million)
mg/l	milligram per litre (concentration)
Ml	Mega litre (1 000 000 litres)
Mm^3	Mega cubic metre (1 000 000 000 litres)
MScEng	Degree Master of Science in Engineering
No. (no.)	Number (number)
NWA	National Water Act (Act 36 of 1998)
O	symbol for the element oxygen
POSWAR(s)	Personal on-site water resource(s)
RAU	Rand Afrikaans University
RSA	Republic of South Africa
s	second (measure of time)
SA	South Africa
SAICE	South African Institution of Civil Engineering
SAP	Systems Applications and Products
SG	Surveyor General
SSA	Statistics South Africa
TDS	Total Dissolved Solids
TMG	Table Mountain Group
TOC	Technical Operations Centre
TPA	Transvaal Provincial Administration
UAW	unaccounted for water
UK	United Kingdom (Great Britain)
UP	University of Pretoria
USA	United States of America

USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USSR	Union of Soviet Socialist Republics
WCED	World Commission on Environment and Development
WDM	Water Demand Management
WDS(s)	Water Distribution System(s)
WISA	Water Institute of Southern Africa
WRC	Water Research Commission
WSDP	Water Services Development Plan

Glossary

Term	Definition
Alluvial	Deposited by flood or sea
Aquifer	Geological formation with structure or texture capable of holding water or permitting appreciable water movement through it
Arenite	Sedimentary (sand) clastic rock e.g. sandstone
Artesian (adjective)	Rising to the surface under internal hydrostatic pressure (of water)
Artesian well	Confined well of which the hydraulic head is higher than the upper impermeable layer of the confined aquifer it is located in
Borehole	A hole sunk into the earth for the purpose of locating, abstracting or using subterranean water and includes a spring, well and wellpoint (CCT, 2006)
Cape	Means Cape Town, the Cape metropolitan area or Cape Peninsula
Casing	Large diameter pipe assembled and inserted into a recently drilled section of a borehole and typically held into place with cement
Cenozoic	Of, belonging to, or designating the latest era of geologic time, which includes the Tertiary Period and the Quaternary Period and is characterized by the formation of modern continents
City	Means the area of jurisdiction of the municipality of the City of Cape Town
Confined well	A cased well that is installed through the upper impermeable layer of a confined aquifer
Consumer	Means any person using water from any installation connected to a pipe which is supplied with water from a main
Domestic	Of or in the home or household
Domestic water	Means water supplied for drinking, ablution and culinary purposes to residential premises
End-use	The smallest identifiable use of water at a stand (Jacobs and Haarhoff, 2004a)
Evaporation	Process by which water passes from the liquid to the vapour state
Evapotranspiration	Loss of moisture from the combined effects of direct evaporation from land and sea and transpiration from vegetation
Erf	Land parcel or plot of land
Erf number	Unique number (within a suburb) that describes a land parcel or property on the Surveyor General's diagram
Flowing artesian well	Confined well of which the hydraulic head is higher than the ground surface
Fountain	*See spring*
Freeware	Software available free on-line
Gardening	Act of cultivating plants, flowers, vegetables, herbs, fruit or a grass lawn at a residential stand

Term	Definition
Geocoding	Process of assigning geographic coordinates, e.g. latitude and longitude, to street addresses as well as other points and features which can then be mapped and entered in GIS format
Geohydrology	Study of properties, circulation and distribution of groundwater – used interchangeably with hydrogeology
Granite	Light-coloured coarse-grained igneous rock consisting mainly of quartz (by volume)
Groundwater	Groundwater is referred to as the water found in the subsurface of the saturated zone below the water table or piezometric surface
Guideline	A document approved and published by the relevant government institution(s) and extensively used by the industry with the aim of guiding decisions and criteria in specific areas (Van Zyl *et al*., 2008)
Hydrogeology	Study of the distribution and movement of groundwater, also called groundwater hydrology
Interstices	Openings or void space in rock formation capable of holding water
Irrigation	Artificial provision of water to sustain growing vegetation e.g. periodic watering of plants, gardens, lawns etc.
Isthmus	Narrow strip of land joining two larger land areas
Lithology	Gross physical characteristics of a rock or rock formation
Meter	*See water meter*
Municipality	Means the municipality of the City of Cape Town
Occupant	*See occupier*
Occupier	Means a person who occupies any premises or part thereof, without regard to the title under which they occupy it
Piezometric surface	Imaginary surface to which groundwater rises under hydrostatic pressure
Peninsula	A neck or an area of land almost completely surrounded by water except for an isthmus connecting it with the mainland
Potable water	Water that is fit for human consumption i.e. drinkable water
Precipitation	Water that falls to the ground, in solid or liquid form, including rain, snow, sleet and hail
Private use	Restricted to personal, residential and on-site water use in particular
Proxy	An authorised agent or surrogate
Recharge	Addition of water to the zone of saturation either by downward percolation of precipitation or surface water or lateral migration of groundwater from adjacent aquifers
Red Book	Guidelines for human settlement planning and design (CSIR, 2003)
Residential	Officially bound to or involving or provided for residence
Residential stand	Means a stand with dwelling or group of dwellings for human residing purposes

Term	Definition
Residents	Includes, and can be substituted by, inhabitants i.e. all the people resident or staying, or deemed to be permanently residing on a stand (Garlipp, 1978)
Riparian	Of or on a riverbank
Saline	Impregnated with salt(s)
SAP system	Software that provides the capability to manage financial, asset and cost accounting, production operations and material, personnel, plant and archived documents
SG code	Unique Surveyor General's 21 digit key for all cadastral land parcels
Spring	A point in the ground where groundwater emerges naturally through the earth's surface, usually as a result of topographical, lithological or structural formation
Stand	A house and the surrounding area within the residential property boundary (Jacobs and Haarhoff, 2004a)
Surrogate	A substitute or a person deputising for another in a specific role
Transpiration	Act or process by which plants give off moisture through the pores of their skin, the surface of leaves and other parts
Typology	The analysis or systematic classification of types or categories that have characteristics or traits in common
Water	Clear, colourless, odourless and tasteless liquid, a compound of hydrogen and oxygen (H_2O) and an essential constituent of all living matter on earth
Water consumption	Measurements of the amount of actual water used (including water that is consumed) by a consumer or group of consumers
Water demand	Amount of water to be put into the supply distribution scheme as required by a consumer or group of consumers
Water meter	Means a device which measures the quantity or volume of water passing through it
Water resource	All water bodies in the hydrological cycle, including a water course, surface water, estuary or aquifer
Water supply	Actual metered quantity of water supplied over a certain period of time to a stand or group of stands
Water table	Upper surface of the saturated zone of an unconfined aquifer at which pore pressure is atmospheric, the depth of which may fluctuate seasonally
Well	In South Africa used to refer to a shallow large diameter hole in the ground for the abstraction of groundwater from primary aquifers, in USA synonymous with borehole *(also see borehole)*
Wellpoint	In South Africa used to refer to a shallow, small diameter hole in the ground for the abstraction of groundwater from primary aquifers, in USA used to refer to the most common method for dewatering or groundwater control

1. Introduction

1.1 Background

Water has been valued indispensable for all forms of life since ancient times. Research has shown that between 60% and 70% of the adult human body consists of water (Burke, 1995), suggesting that there is an important link between water and human life. Without this seemingly invaluable compound comprised of hydrogen and oxygen, life on earth cannot exist. Water is thus essential for everything on our planet to grow and prosper (Nkwonta and Ochieng, 2009).

The effective application of fresh water, which is a scarce resource, is therefore vital. This is especially true for geographical regions where water demand is increasing, while available water resources are reaching the limit (Jacobs, 2008a). Southern Africa is such a region, with water supply being limited, unevenly distributed and negatively impacted by climate change (Blignaut *et al*., 2009).

South Africa can therefore be regarded as a semi-arid country (Walmsley *et al*., 1999) with the average rainfall a mere 497 mm annually, which compares adversely with the global average of 860 mm per year (Rosewarne, 2005). Woodford *et al*. (2005) reported that some 21% of South Africa receives less than 200 mm per annum ranking it amongst the twenty most water-scarce countries in the world

The majority of the rain falls in a narrow belt along the eastern and southern coasts of South Africa, while the rest of the country on average receives only about a quarter of the total rainfall a year. In addition, hot, dry conditions result in a high evaporation rate (WRC, 2008). Periods of severe drought in certain parts of South Africa have therefore been a common feature.

The Western Cape Province of South Africa is considered a water scarce area (Frame and Killick, 2004). Although the establishment of a European settlement in the Cape by Dutch mariners in the 17th century was based on the availability of surface water resources the situation has changed dramatically since then, as a direct result of urban development, the ever-increasing population of the Cape Metropolitan Area (CMA) and, to some extent, climate change.

The Cape Peninsula is situated at the southern tip of Africa and has a Mediterranean type climate, meaning the area receives winter rainfall and experiences hot and dry conditions during summer months (Mlisa, 2007). Cape Town had a mean annual rainfall of 515 mm for the period from 1961 to 1990 (Schulze, 1986) and, although more than half the global average, it is mostly confined to the cold winter months making the occurrence of droughts in the Peninsula relatively frequent. The first drought on record in the Cape was in the summer of 1663 (Wilson, 2002).

Droughts in the Cape normally occur in summer, due to below average rainfall during the preceding winter season. The hot and dry summer seasons are typically the periods when water demand is highest, because of higher temperatures and the fact that the watering of gardens is the norm in most residential areas (CCT, 2001a). This contrast results in critical water shortages which often lead to the implementation of water restrictions by local authorities as means to achieve reduced water consumption and alleviate the situation.

Most of the water in the CMA is derived from surface water sources (Saayman and Adams, 2001) which amplify the aforementioned contrast even further during periods of droughts and water restrictions. However, according to Maclear (1995) the Cape Peninsula is largely underlain by an extensive primary, unconfined aquifer of significant exploitation potential. Its unconsolidated sand and shallow water table provide ideal conditions for small-scale groundwater abstraction. Many owners of properties situated above the aquifer unit have capitalised on this situation and utilise groundwater as an alternative to potable water, mainly for garden irrigation purposes (Maclear, 1995).

1.2 Focus of this study

On-site groundwater abstraction and the use thereof are relatively common in South Africa (Jacobs *et al*., 2011). Considering the notable impact of residential groundwater usage on water distribution systems, combined with the prevalence thereof in South

Africa, it is astonishing to note the acute lack of research into the topic to date. Although it has been investigated to a certain extent in the past, currently very little research and published work on this topic exists either locally or abroad.

The primary problem at local authority level is considered to be the development of a method to identify, obtain and prepare information regarding private groundwater usage for further analysis, as well as the impact thereof on potable water consumption from the municipal supply system.

The focus of this study falls on serviced residential properties in the Cape Peninsula with access to groundwater, utilised mainly for garden irrigation and, to a lesser extent, maintenance purposes. However, the typology and trends of private groundwater usage and the residential stands where it is practised is largely an unknown field.

The main aim is therefore to determine the theoretical impact that this practice has on the municipal water demand of residential stands with access to groundwater within the study area in view of future research needs. The study aims to prove that groundwater usage at such stands, on average and for various stand size categories, directly leads to an expected reduction in the metered use of potable water from the municipal supply system.

A consumer's overall water demand, however, does not necessarily remain constant on average and in actual fact the use of freely available groundwater could lead to an increase in the total water consumption at these stands. Either way, the general perception remains that the groundwater component being used replaces a certain portion of what would otherwise have consisted mainly of potable water.

Currently no complete or up-to-date records are available from local authorities as to the location or number of stands where groundwater is used within the study area. This study therefore aims to aid the situation and provide a better understanding of the scope and effect of residential groundwater use.

1.3 Motivation and key objectives of this study

The key motivation behind this study is to remedy the lack of knowledge that exists on the expected impact of serviced residential groundwater use on the municipal water consumption at such stands within the study area. The main objective is to determine the average extent of the expected reduction in potable water demand that this practice brings about, rather than the estimated volume of groundwater used over a certain period in a specific suburb or area. The study therefore does not aim to put forward a set of guidelines for the estimation of residential water demand at stands where groundwater is utilised as alternate water source.

The outcome of this research could help present a better understanding as to the potential of groundwater use at residential stands in the study area, but possibly also assist with future water demand estimates where the average reduction in residential water consumption due to this activity is incorporated by addition to the average water use per stand, according to the guidelines applicable at the time.

Reasons for the addition of a groundwater component to water demand estimates could be to make provision for periods when electricity supply is disrupted (e.g. power failures or load shedding), lower water tables due to poor rainfall in the wet season, possible future legislation that prohibits the private use of groundwater sources, defective pumping equipment or cases where residents at stands with groundwater abstraction points (GAPs) use it to a lesser extent than previous occupants did.

Furthermore, peaks in water distribution systems are attenuated by the watering of gardens and grass areas during times of peak water demand i.e. mornings and late afternoons or early evenings during weekdays. This means that, essentially, water consumption during peak times in residential areas is effectively reduced through the use of groundwater for irrigation purposes. The results of this study may therefore serve as an indicator towards the potential of residential groundwater use as a valuable water demand management tool for the future if promoted, utilised, managed and regulated properly.

1.4 Scope and limitations of the investigation

The study area for this investigation includes the greater Hermanus area and the six administrative areas within the City of Cape Town (CCT) municipal jurisdiction at the time of this study namely Blaauwberg, Cape Town City, Helderberg, Oostenberg, South Peninsula and Tygerberg, as depicted in Figure 1.1 below. It therefore includes the town of Atlantis (which falls under the Blaauwberg local municipal council), while the Stellenbosch municipal area is excluded from this study.

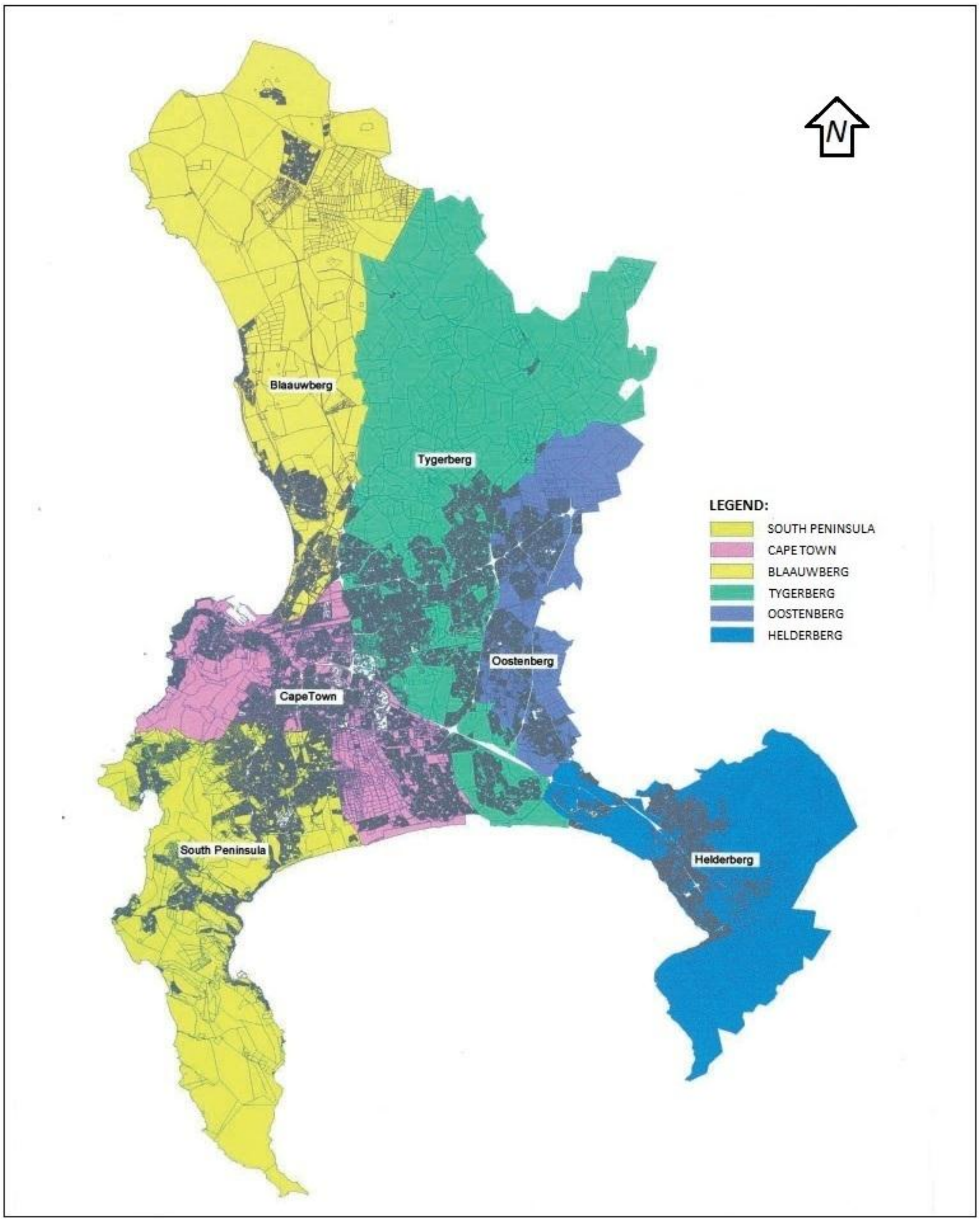

Figure 1.1: Administration areas of the City of Cape Town

Source: CCT (2005)

Data for the town of Hermanus was used in a pilot study to test the proposed methodology which is to be used for the analysis of the Cape Town data and to assess the outcome when applied to the identified group of stands in Hermanus. These two areas (Hermanus and Cape Town) were chosen merely due to the availability of data for stands with access to on-site groundwater.

The main study (not the pilot study) is limited to stands of addresses obtained from a fairly recent CCT registration process for the on-site utilisation of non-potable water sources, which was carried out between 2000 and 2006. No additional surveys to contact, identify or verify any other residential erven with access to groundwater in the study area were conducted during this study.

It is further restricted to include only serviced residential stands in the above areas, to which municipal water is supplied through individual consumer meters as the annual average daily demand (AADD) of each property that forms part of the study is required for further processing and a comparative analysis with water demand guidelines. Therefore non-residential stands and stands for which no water consumption data was available at the time were not included.

It is beyond the scope of this study to physically assess, log or meter the average yield of groundwater abstracted at the identified stands where it is being used as alternate water source. This was not considered mainly due to the impracticality thereof, the relatively high cost of water meters and the plumbing complexities it would require.

Although the quality of groundwater largely determines the end-use for which it can be applied, i.e. potable or non-potable purposes, investigation into the quality and need for treatment of water from this source is beyond the scope of this study.

Lastly, the different types of application of groundwater at the selected stands under investigation were also not determined as part of this study, as this would require an extensive survey and participation from residents of all stands in the data set in order to obtain the necessary information.

1.5 Approach and methodology

This report is structured around the occurrence of residential stands with access to groundwater and the investigation into the expected impact the use thereof has on municipal water demand. It is divided into the following primary components:

- Description of some fundamental concepts related to the topic of this study, including the hydrologic cycle and general hydrogeology;
- Overview of groundwater quality, the most common methods for abstracting groundwater, groundwater use in South Africa and its potential environmental impacts;
- Literature review of water use in South Africa, the domestic water use profile of the CMA, elasticity of residential water demand and guidelines for the estimation of water demand;
- Discussion of private groundwater use and the legal aspects related to it, including the advantages and applications of GAPs at residential stands;
- Elaboration of the underlying geology of the Cape Peninsula, recent water restrictions in the CCT municipal area, and the CCT registration process for the use of non-potable water from on-site sources;
- Chronological review of past research work addressing the topic of private groundwater use and the impact this practice has on potable water demand concludes the literature study;
- Pilot study on residential groundwater use in the town of Hermanus, which serves as a base for the full-scale investigation in the Cape Peninsula and aims to test the proposed methodology and expected outcomes of this research on a smaller scale;
- Explanation of methodology for the identification of residential stands with GAPs in the Cape Peninsula through the verification of the data obtained from the CCT's registration process for the private use of non-potable water;

- Geocoding of all verified addresses in order to plot them spatially with the use of a suitable geographic information system (GIS) program;
- Manual verification of all plotted stands in the spatial environment and linking them with the spatial attributes such as stand size, position and the unique Surveyor General's (SG) code;
- Obtaining the water consumption figures of these properties by using the list of SG codes to extract this data from a commercial software package that incorporates consumer information from treasury data bases; and
- Comparison of the actual water demand of residential stands with GAPs identified during this process with recently published guidelines that are based on historical water consumption records.

The comparative analysis was done by plotting the actual water consumption of the stands with access to on-site groundwater sources is used and various water demand guidelines against stand size for simple comparison. The results of the analysis are presented graphically, briefly discussed and conclusions drawn based on the findings of this investigation.

1.6 Assumptions

The approach of this study requires that various assumptions be adopted to allow the processing and analysis of the available data. Most of the assumptions are directly related to the extensive process that the CCT undertook between the end of 2000 and mid 2006 for the registration of private use of non-potable water during a period of various water restrictions throughout all CCT municipal areas. These assumptions are briefly described below:

- It is unlikely that all residential stands with access to private GAPs and where groundwater is utilised in the CCT municipal area were registered, or that the information made available to this study includes all those stands where this is the case. However, for the purposes of this study, it is assumed that water from on-site groundwater sources is used only at the residential stands for which GAPs were registered;

- It is assumed that on-site groundwater was actively used at all residential stands with GAPs that were registered, which is concluded from the fact that these stands were willingly registered by the relevant owners or residents, most likely since groundwater from the GAPs registered was used regularly at the time of registration;

- It is further assumed that all GAPs on registered residential stands were still actively used for on-site abstraction and utilisation of groundwater as a supplementary water source during the period of collection of the actual water consumption data used in the comparative analysis of this study;

- No distinction is made between the various types of GAPs (e.g. wells, wellpoints and boreholes). Therefore, for the purposes of this study, it is assumed that all GAPs registered are used for similar purposes and to the same extent, regardless the type; and

- In order to make any comparative analysis viable it is accepted that the water demand guidelines used for the comparison (of the mean AADD of residential stands with GAPs identified through the CCT registration process) is an accurate reflection of the true average potable water demand and consumer patterns of residential stands in the study area.

1.7 Definitions of key terms

So as to ensure that only one meaning is attached to certain terms and phrases used in this thesis it is essential that these are defined from the outset. Differences exist between terminology used in the United Kingdom (UK), United States of America (USA) and South Africa, and certain words in this thesis will be used only as defined herein and will not necessarily have the same meanings as used abroad or in other literature. Hence the meaning of some key terms relevant to this study is discussed briefly hereafter.

1.7.1 Definition of the term "residential stand"

The adjective "residential" is defined in the Oxford dictionary as "being bound to, involving or provided for official residence". It is considered synonymous with the word "domestic", which carries the definition of "in or of the home or household", as given by the same dictionary.

The term "stand" has been defined as a plot of land (Van Zyl *et al*., 2008) and by Garlipp (1978) to include, inter alia, erf, plot, site or any piece of ground, the extent of which can be measured or determined and on which any form of building appears. The phrase "any form of building" used in the this definition may be replaced with the term "dwelling" to specifically refer to a residential stand with a dwelling being any form of abode or residence, whether a house, shanty or flat as given by Garlipp (1978).

Jacobs and Haarhoff (2004a) however defined a "stand" explicitly as a house and the surrounding area within a residential property boundary which inherently gives it a residential connotation and thus excludes non-residential stands. The expression "residential stand", where used in the text of this thesis, will therefore bear the meaning of a plot of land with a dwelling unit on it that is occupied for official residence purposes only.

1.7.2 Water consumption versus water demand

A clear difference exists between the terms "water consumption" and "water demand". Water consumption means measurements of actual water used, or estimated measurements of water that will be used, expressed as a volumetric quantity.

In order to determine the water consumption of an individual consumer, a stand, suburb or entire city, accurate metering or measurements are essential. Water consumption at serviced residential stands is measured through water meters of which the readings are recorded on the municipal treasury database. Garlipp (1978) reported that the water consumption on residential stands increases with stand size, annual income and number of household members.

Garlipp (1978) also defined the phrase “water demand” as the actual or estimated need for water for useful purposes, thus excluding provision for losses i.e. leakage or wastage, if no limiting factors of technological or economic nature are applicable.

Water demand can therefore be expressed as either a rate or quantity and is commonly presented and reported as a normalised average yearly value known as the “average annual daily demand” or the widely used acronym for it that is AADD. Residential water demand is obtained when the AADD of an area under investigation is limited to a sector comprising residential consumers only (Jacobs, 2008b).

Therefore, for the purposes of this study, the phrase “water demand” shall refer to the demand for potable water from the municipal supply system of a single residential stand or selected group of residential stands only.

1.7.3 Meaning of the phrase “water saving”

The phrase “water saving” should be viewed in the correct perspective. The word “save” is defined as “to avoid the spending, waste or loss (of something)” and “to treat with care so as to preserve” (Collins, 2004). For this reason the term “water saving” is often used in relation to a reduction in water demand and not actual water use.

Consumers may be “saving” water by making use of more effective means e.g. on-site boreholes and wellpoints, rainwater harvesting or greywater re-use. This leads to a “saving” being recorded as a result of a reduced municipal water meter reading, despite the actual volume of water used by end-users on the property not necessarily changing (Jacobs *et al*., 2007).

In fact, as reported by Simpson (1990), the total volume of water used at stands with private boreholes may even be higher, although the metered water use shows a reduction in the volume of water from municipal supply that is consumed, when compared to that of other similar stands where groundwater is not utilised as an alternative water source.

However, for the purposes of this study, the change recorded by the municipal water meter at a particular stand with a metered water connection is considered to represent a change in the consumer's water use. Any reduction in a consumer's metered water use, that is a saving in the volume of potable water from municipal supply being used at a residential stand, is thus considered to constitute a water saving.

1.7.4 Discussion of the term "garden borehole"

The term "garden boreholes" refers to privately owned GAPs on residential properties which are installed, managed, operated and maintained by the home owner or resident (Saayman and Adams, 2001).

The connotation with the word "garden" emanates from the fact that residential GAPs are located outside and used mainly for garden irrigation. Therefore, where the term "residential GAPs" or "private GAPs" is used or referred to throughout this text it refers to "garden boreholes" used to abstract groundwater at residential stands, regardless of whether it is an open well, wellpoint or borehole.

1.7.5 The acronym GAP - groundwater abstraction point

Groundwater can be abstracted via some type of "structure" delivering it from under the ground to the surface above, e.g. boreholes, wellpoints and wells. An introductory description of the various types of these "structures" is given as part of the literature review to follow later in this text without further elaboration thereafter.

However, to avoid any confusion the term "groundwater abstraction point" (GAP) will instead be used throughout to describe any type or method of abstraction of groundwater. In this study the type of GAP is not considered noteworthy and the acronym GAP is adopted from Wright and Jacobs (2010) to describe any type of groundwater abstraction.

1.7.6 Elaboration of the expression "stands with GAPs"

The expression "stands with GAPs" is used frequently throughout this thesis and refers specifically to those residential stands where access to private groundwater sources was registered during the CCT's recent GAP registration process. The water use at these properties formed the data base of the analyses in this research project and the subsequent results for such stands were interpreted as an indication of the water demand at stands where the private use of groundwater in addition to potable water is considered to be common.

No information was available or could be gained during this research to assess whether the registered "stands with GAPs" indeed have access to groundwater, or whether those stands not registered do not use or have access to groundwater. However, for the purposes of this study, the phrase "stands with GAPs" shall mean those stands considered to have access to groundwater sources.

To date, the dataset from the CCT's GAP registration process was the only available data of this magnitude in terms of the number of properties (registered) and was considered suitable for research into this topic despite the various limitations it posed and assumptions made.

2. Literature review

2.1 Fundamental concepts

2.1.1 Hydrologic cycle

The hydrologic cycle, in plain terms referred to as the water cycle, describes the continuous circulation of water on, above and below the surface of the earth as shown on Figure 2.1 below. The hydrologic cycle has no hypothetical beginning or end and should rather be seen as a continuous and never-ending process.

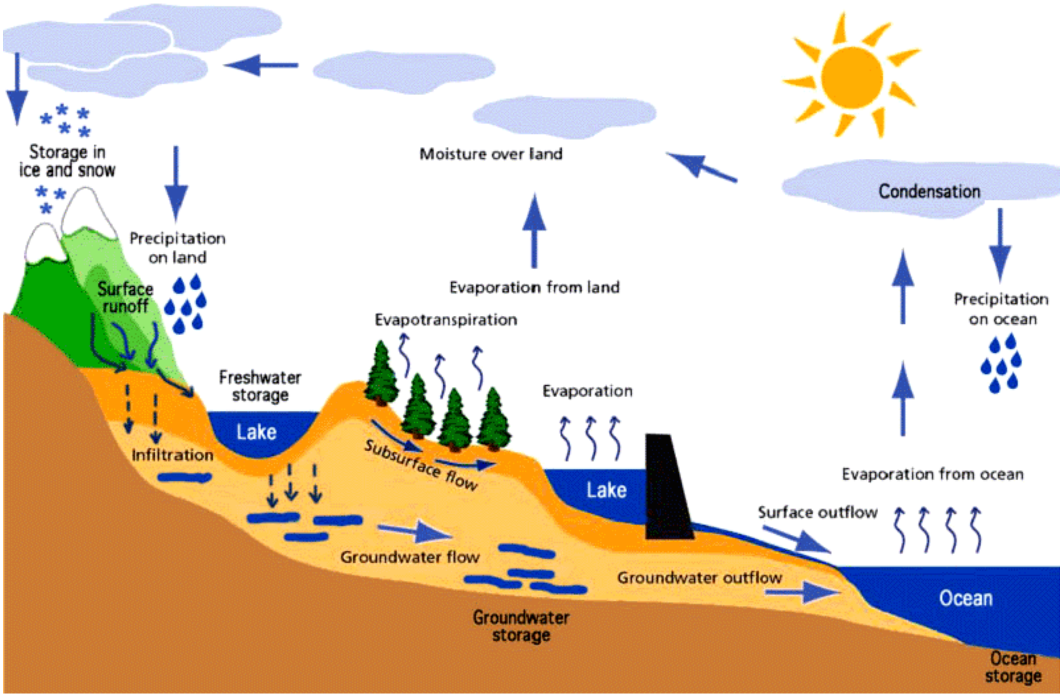

Figure 2.1: The hydrologic cycle

Water evaporates from surface water on land and the ocean. Transpiration by plants also releases vapour into the atmosphere. The processes of evaporation and transpiration are jointly referred to as evapotranspiration. Water eventually returns to earth through a process called precipitation, meaning water that falls to the ground, in solid or liquid form, including rain, snow, sleet and hail.

Moisture moves through the atmosphere, condenses and forms droplets under suitable atmospheric conditions. When the drops develop and become too heavy to remain aloft in circulation, water falls to earth – better known as rain when in liquid form. Snow and hail again, form under low-pressure conditions with an upward motion of air, when the droplets crystallise into ice particles and fall to earth in solid form.

Some of the rain that falls on land, and also melted snow, will drain across the surface into streams, rivers, dams, lakes and the ocean, which is termed overland flow. Where the surface soil is porous, water seeps into the ground through a process described as infiltration.

Infiltrated water gravitates to a depth where the underlying soil or rock is saturated with water. Groundwater flows through the soil and rock layers until it discharges as a natural spring or through seepage into streams, rivers, lakes and the ocean. At this point a full hydrologic cycle has been completed and the process starts all over again.

2.1.2 Hydrogeology

Hydrogeology, used interchangeably with the term geohydrology, is defined as the study of groundwater distribution and movement. Some general hydrogeological terms are briefly discussed below.

2.1.2.1 Groundwater

Groundwater is by far the largest source of fresh water on earth (Virginia, 1995). The term groundwater refers to the water found in the subsurface of the saturated zone below the water table or piezometric surface. The water table marks the upper surface of the saturated zone of groundwater systems (DWAF, 2004a).

More than 70% of our planet is covered with water. Saline water in the oceans and underground (through seawater intrusion) accounts for roughly 97.5% of all water on earth, with land areas holding the mere 2.5% balance of fresh water supply. Of this fresh water about two thirds is in the form of glaciers and permanent snow cover. Table 2.1 shows the distribution of water resources on earth and the large contribution groundwater makes to the world's total fresh water supply.

Table 2.1: Contribution of groundwater to global water distribution

Water source	Water volume (km^3)	Percentage of total water volume
Oceans	1 338 000 000	96.50%
Ice caps, glaciers, permanent snow	24 064 000	1.74%
Groundwater	23 400 000	1.70%
Fresh	10 530 000	0.76%
Saline	12 870 000	0.94%
Soil moisture	16 500	0.001%
Ground ice and permafrost	300 000	0.022%
Lakes	176 400	0.013%
Fresh	91 000	0.007%
Saline	85 400	0.006%
Atmosphere	12 900	0.001%
Swamp water	11 470	0.008%
Rivers and streams	2 120	0.0002%
Biological water	1 120	0.0001%
Total water volume	**1 385 984 510**	**100%**

Source: USGS (2005)

Groundwater plays a key role for humankind and the environment. During droughts, groundwater is often the last attainable water source, whereas in wet periods, groundwater systems are naturally replenished through infiltration of surface water when this recharge reaches the water table. This makes groundwater a vital resource which can act as natural storage and a buffer against shortages in surface water.

2.1.2.2 Aquifers

An aquifer is the term used for an underground geological formation with structure or texture that is capable of holding water or which permits appreciable water movement through it (NWA, 1998). Over 80% of South Africa is underlain by relatively low-yielding, shallow, weathered or fractured-rock aquifer systems (Woodford *et al*., 2005). The major aquifers include the dolomites of the West Rand and the Table Mountain Group sandstones and coastal sands of the Western and Eastern Cape.

The following three main aquifer types are generally recognised (DWAF, 1998):

- Porous or “primary” aquifers;
- Fractured or “secondary” aquifers; and
- Dolomitic aquifers.

In South Africa the definition of a primary aquifer as given by DWAF (2004a) is “an aquifer in which water moves through the original interstices of the geological formation”. In USA it is used to refer to “an aquifer currently being used by a major municipal water supply system”. A primary aquifer could consist of consolidated or unconsolidated material.

Secondary aquifers are “aquifers in which water moves through secondary openings and interstices which developed after the rock formations were formed” i.e. through weathering, faulting or fracturing due to tectonic activity (DWAF, 2004a). These faults and fractures form the secondary permeability of such aquifers. Examples of secondary aquifers in the Cape Peninsula are the Table Mountain Group (TMG) aquifer and aquifers within the Malmesbury Group rocks.

Dolomitic aquifers are secondary aquifers as they generally develops from a fracture system which is eroded by chemical dissolution to form large cavities in the rock formation e.g. in areas along the West Rand.

The characteristics of aquifers vary with the geology and structure of the substrate in which it occur. Generally, the more productive aquifers occur in sedimentary formations and unconsolidated materials e.g. gravel, sand and silt, in comparison to weathered and fractured rock units, that yield less groundwater.

The two main aquifer categories are those of confined and unconfined aquifers. A confined aquifer is overlain by a relatively impermeable layer of rock or substrate that transmits no or very little water. An unconfined aquifer is permeable and has no confining layer between the saturated zone and ground surface, therefore allowing the water table to fluctuate freely.

The majority of confined aquifers are classified as artesian because the hydraulic head in a confined well is higher than the level of the upper impermeable layer of such an aquifer. If the hydraulic head in a confined well is higher than the ground surface it is referred to as a "flowing" artesian well, as with a natural fountain.

2.1.2.3 Groundwater recharge

Groundwater recharge is the addition of water to the zone of saturation either by downward percolation of water or lateral migration of groundwater from adjacent aquifers (DWAF, 2004a).

Alley *et al*., (1999) stated that "under pre-development conditions, a groundwater system is in long-term equilibrium and recharge equals discharge". Groundwater recharge occurs either naturally through infiltration of water through unsaturated material to the water table from precipitation (i.e. rainwater and melted snow) and surface water (i.e. streams, rivers, dams, lakes and wetlands), or artificially when reclaimed water is routed to the subsurface.

Recharge may be impeded to some degree by human activities, including impermeable artificial surfaces, urban development or borehole logging, which can result in enhanced surface runoff and reduction in recharge.

Extensive use of groundwater may lower water tables locally during dry periods when groundwater is abstracted on a large scale e.g. rate of abstraction is higher than tempo at which the aquifer is recharged, or in the event of several GAPs in relative close proximity being used for prolonged intervals.

Groundwater recharge is therefore a vital process in this regard as the volume-rate abstracted from an aquifer must be less than the volume-rate it is recharged with, to ensure sustainable groundwater availability and management.

2.2 Quality of groundwater

The quality of groundwater can be simply defined as its suitability for a specific use (Fetter, 1980). Any solute that enters the hydrologic cycle through human actions is referred to as a contaminant; if it renders the water unfit for use, it is a pollutant. Even small concentrations of some toxic substances may be highly detrimental to water quality.

The term “water quality” was coined with reference to the quality of water required for human use: “good quality” water is “clean”, unpolluted and suitable for the intended use i.e. drinking as well as agricultural and industrial purposes (Nkwonta and Ochieng, 2009). A better descriptive and widely used term for this is “potable water” which refers to water fit for human consumption regardless the source.

Potable groundwater is available across most of South Africa in sufficient quantities to supple small to medium scale domestic requirements, stock watering and irrigation (Rosewarne, 2005). Proper sampling and laboratory testing must be done before groundwater is consumed and repeated on a regular basis to determine whether the specific groundwater source is indeed still potable.

Groundwater has long been considered to be of excellent quality because of the soil barrier providing effective isolation of this high quality source water from surface pollutants. However, both inorganic and organic chemical compounds that enter the subsurface environment can be transformed by microbiological processes which can lead to precipitation or dissolution of phosphates and heavy metals, as well as oxidation or reduction of iron and sulphur salts (Engelbrecht, 1998).

Thus the quality of groundwater is not necessarily such that it is suitable for potable use without prior treatment. Groundwater should be boiled to exterminate all micro-organisms possibly present in the water or alternatively be disinfected with suitable chemicals before it is consumed. It should also be filtered to remove any solid particles.

Groundwater quality is subject to degradation by chemicals and biological pollutants, while it remains the principal factor determining the possible applications of the water. Non-potable groundwater abstracted at serviced residential stands is therefore limited mainly to outdoor applications e.g. garden irrigation and uses other than for human consumption, unless treated on site. This nonetheless makes it a popular alternate water source.

2.2.1 Groundwater pollution

Groundwater pollution results in the alteration and degradation of the natural quality of groundwater (Sililo *et al*., 2001). Groundwater pollution threatens many valuable water resources and occurs widely, from a variety of anthropogenic sources. These include point sources such as landfill sites, waste disposal facilities, industrial pollution, wastewater treatment works, on-site sanitation systems and cemeteries.

According to Foster *et al*. (1998), urban groundwater abstraction is known to have evolved away from cities as urban aquifers become contaminated. Changes in land use, such as the clearing of vegetation, over-abstraction of groundwater or excavation below the water table, can also contribute significantly to groundwater pollution (Tredoux *et al*., 2004).

The consequences of groundwater pollution are often more serious than for surface water, due to the relatively long subsurface residence times. Harmful pollutants in groundwater can also go undetected for years, as they may be colourless, odourless and tasteless (Virginia, 1995), while remediation is difficult and costly, sometimes even impossible.

2.2.2 Iron content

Iron (Fe) is a common metallic element and an essential trace constituent for both plant and animal growth (Fetter, 1980). The most common sources of iron in groundwater are naturally occurring from weathering of iron bearing rocks and minerals.

Well-oxygenated surface waters normally contain almost no dissolved iron. Some groundwater, however, is devoid of oxygen and thus contains ferrous iron. Carbon dioxide reacts with iron in the ground to form dissolved ferrous bicarbonate which, in water, produces soluble ferrous (Fe^{2+}) ions. Groundwater containing ferrous iron is clear and colourless when drawn.

Once groundwater containing ferrous iron reaches the surface, the ferrous ions are oxidised when it is exposed to air and reacts with the oxygen. As carbon dioxide is released from the water, oxygen combines with the ferrous ions to form insoluble ferric (Fe^{3+}) ions. The oxidised ferric iron particles are a reddish brown colour that is generally visible in water.

The oxidation of ferrous iron to ferric iron is represented by the following chemical equation:

$$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O$$

The above equation shows the chemical reaction of aqueous ferrous ions with oxygen and acidic hydrogen ions i.e. protons (H^+) to form ferric ions and water (H_2O).

The oxidised ferric iron in groundwater precipitates when this water is used, which is evident from the rust-brown coloured staining of plumbing, walls, surfaced areas and other fixtures in such cases. This is a common sight in many areas of the Cape Peninsula where groundwater is commonly used as supplementary water source for garden irrigation. It is, however, perfectly safe for use on lawns and plants and does not affect soil quality (CCT, 2010).

2.3 Groundwater abstraction

2.3.1 Methods of groundwater abstraction

The term “geosite” is used frequently in Department of Water Affairs (DWAF) terminology and refers to all types of GAPs, whether natural or artificial.

A geosite is defined by Xu *et al*. (2003) as “a naturally occurring or artificially excavated or constructed or improved underground cavity” which can be used for one or more of the following purposes:

- intercepting, collection or storing of water in, or removing water from, an aquifer;
- observing and collecting data and information on water in an aquifer; or
- recharging an aquifer.

Although boreholes represent the most common type of geosite, it is relevant to recognise that there are many other features related to groundwater abstraction, occurrence and monitoring as seen in Table 2.2.

Table 2.2: Different “geosite” types

Descriptor	
Borehole	Mine
Well	Seepage pond
Wellpoint	Spring
Drain	Sinkhole
Tunnel	Lateral collector

Source: DWAF (2004b)

The geosites listed in Table 2.2 have various possible applications. However, only wells, wellpoints and boreholes are commonly used to withdraw groundwater for municipal, agricultural, industrial and private purposes and these will each be discussed briefly.

2.3.1.1 Wells

A well is defined in the Oxford dictionary as “a shaft sunk into the ground to obtain water, oil or gas”. In the United States of America (USA) this term is used to describe all types of groundwater abstraction structures excavated in the ground, regardless the purposes they are used for and does not only refer to primitive hand dug wells. In South Africa the term “well” is used specifically to refer to a shallow, large diameter open hole in the ground used to abstract groundwater (DWAF, 2004a).

Wells are the oldest artificial structures used to access groundwater. These relatively shallow, large diameter pits are dug by hand to below the water table. Upon excavation, the hole is lined with laid stones or brickwork, extending this vertical lining into a wall around the perimeter of the well opening. The water is traditionally drawn up from the well to the surface using buckets or a hand pump.

Hand excavated wells provide a cheap and low-tech solution to access groundwater, although it is not suited to areas of underlying hard rock formations. Since most hand dug wells exploit shallow aquifers, they are often susceptible to yield fluctuations when the water table drops to a level below the bottom of a well.

These types of well are nevertheless cost effective compared to boreholes and other methods of construction, since they require mostly physical hand labour. Wells also have low operational costs and require a minimum level of maintenance, making this an attractive method for groundwater abstraction in rural locations

2.3.1.2 Wellpoints

The term wellpoint or “tube well” as referred to by Lomberg *et al*. (1996) is a shallow, small diameter hole in the ground used to abstract groundwater from primary aquifers (DWAF, 2004a). In the USA this term is synonymous with the dewatering of excavations. Wellpoint systems are probably the most common method of groundwater control, as they are applicable in a wide range of excavations and groundwater conditions (DANAF, 1983).

A wellpoint is essentially a small well of approximately 50 mm diameter with a slotted screen at the bottom connected by a riser pipe to a vacuum pump that is used to raise the water from the bottom of the well to ground level. The pump is not actually applied to the soil, but groundwater drains from the soil through the screen and is then lifted to the top (Powrie, 1997).

Another description of a wellpoint, as defined by CCT (2006), is a small diameter pipe jetted into unconsolidated sandy or gravelly formations, with a pump situated at ground level to lift and distribute the groundwater. The bottom end of the pipe is slotted to allow sand-free water to flow into the wellpoint, from where it is pumped to the surface. This is probably a definition more suited to the local terminology.

Wellpoints are relatively simple to install and operate. A wellpoint is installed using a hardened drive point and perforated pipe which is either jetted into the ground using pressurised water or physically driven down to the water table with repetitive hammer actions. Pipe sections are added as the drive point reaches deeper into the ground. Once groundwater is encountered the well is washed of sediment and a surface mounted pump installed.

Wellpoints are dependent on the nature of the ground conditions they are installed in, but the installation cost is considerably less than that of boreholes. Although they are not installed to serve large scale municipal needs and usually have a lower yield than a borehole, it is generally adequate for watering small to medium sized gardens.

2.3.1.3 Boreholes

The main method of abstracting groundwater is by means of boreholes. Boreholes are high yielding features that are equipped with submersible or vertical turbine pumps supplying irrigation, urban, mine and industrial requirements (Rosewarne, 2005). Vegter (2001) estimated that by the turn of the previous century there were in the order of 1.10 million water yielding boreholes in South Africa.

The term “borehole” as defined in the City of Cape Town water by-laws means a hole sunk into the earth for the purpose of locating, abstracting or using subterranean water and includes a spring, well and wellpoint (CCT, 2006). According to

Pietersen (2005), in South Africa a borehole is rather one with a yield of more than 0.10 l/s, which is sufficient to supply a small rural community, using a hand pump.

However, in the everyday local tongue a borehole is the generalised term used to refer particularly to a vertically drilled cavity in the ground. Hence, in practice, a clear distinction exists between a borehole and other well types.

Boreholes are installed using a drilling rig. Most drilling machines, either rotary or percussion, are mounted on large trucks, trailers or tracked vehicle carriages. The machinery and technique to advance a borehole varies considerably according to manufacturer, geological conditions and the intended purpose thereof.

Drilled wells can be installed through most geological conditions and can thus reach groundwater at much greater depths than dug wells and wellpoints. Subsequently, the installation costs of boreholes are very high compared to those of wellpoints.

2.3.1.4 Other methods

Other groundwater abstraction methods that also exist, but are used less frequently in practice, include the following:

- windpumps are a familiar sight, especially on farms and in arid parts of South Africa with extensive but generally low-yielding aquifers; and
- springs or fountains (i.e. flowing artesian wells) are points in the ground where groundwater emerges naturally through the surface of the earth, usually as a result of topographical, lithological or structural formation.

However, these methods are not synonymous with groundwater abstraction at residential stands for private use and will therefore not be discussed in more detail.

2.3.2 Groundwater use in South Africa

South Africa has limited water resources that are unevenly distributed across the country (Sililo *et al*., 2001). According to Parsons (2000), groundwater may comprise up to 30% of the total available water resources of South Africa. However, the real value of groundwater is probably not defined by volume but rather local availability, affordability and, certainly, quality.

Groundwater is widely and variably used across the whole of South Africa (Woodford *et al*., 2005) and is withdrawn on a daily basis for personal, communal, municipal, agricultural, industrial and recreational purposes through the operation of open well pits, wellpoints or boreholes.

GAPs are synonymous with main and supplementary water sources for many areas and households mainly due to it being a relatively dry and drought prone country. In terms of South Africa's overall water consumption, groundwater contributes only some 15% of the total volume consumed (DWAF, 2002). This percentage belies the fact that around 65% of the population, including more than 300 towns and settlements, are entirely dependent on this resource as main water supply (Woodford *et al*., 2005).

The annual volume of groundwater used in South Africa has been estimated by various researchers to be somewhere between 1 700 and 2 000 Mm^3/a, mainly for irrigation purposes (Rosewarne, 2005). However, a detailed breakdown of groundwater use in South Africa per sector is presented by DWAF (2004c) which estimated that agricultural irrigation accounts for roughly 64% of all groundwater used in South Africa. The figures of this breakdown are shown in Table 2.3 below.

Table 2.3: Groundwater use in South Africa per sector

Sector	**Annual volume (Mm^3/a)**	**Percentage of total volume (%) ***
Urban domestic	153	8.60
Rural domestic	144	8.10
Agricultural irrigation	1 137	64.20
Stock watering	111	6.30
Mining	156	8.80
Industrial	65	3.70
Other	5	0.30
Total	**1 771**	**100**

* Column added additionally by author to illustrate percentage per sector

Source: DWAF (2004c)

Speaking at a recent groundwater conference, Pietersen (2005) said that groundwater is an important water source to many rural areas and it is estimated that more than 400 communities in South Africa are dependable on groundwater for domestic purposes. He further stressed that groundwater has much potential in serving communities in arid areas where basic water infrastructure does not exist.

2.3.3 Environmental impacts of groundwater abstraction

Sustainability is a key principle in South Africa's National Water Act (NWA) (Act 36 of 1998). Numerous tools are provided by the Act to facilitate sustainability, although defining sustainability is not one of them (Seward *et al*., 2006).

The classic definition of sustainable development in general, given by the *Brundtland Commission* (WCED, 1987), is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Ensuring sustainability in the groundwater field poses a number of challenges.

2.3.3.1 Drop in groundwater levels

Over-abstraction occurs when relatively large volumes of groundwater are abstracted in close proximity and in areas with a low recharge rate (DWAF, 2007). This can cause water table levels to drop, which may lead to the following (Parsons, 2000):

- reduced spring, stream and river flows;
- saline intrusion in coastal areas and hence aquifer degradation; and
- negative impact on sensitive ecosystems such as wetlands.

The cone of drawdown formed during abstraction from a GAP may extend to other GAPs situated nearby when over-abstraction occurs. This may lead to the lowering of water levels in surrounding GAPs, to such an extent that neighbouring GAPs cannot be used simultaneously (Langton and Raymer, 1994).

In South Africa, examples of significant decline in groundwater levels due to large-scale abstraction which have been recorded include the Uitenhage artesian basin and the town of Dendron in Limpopo province (Parsons, 2000). Proper monitoring and management of aquifers can prevent or reduce this impact.

2.3.3.2 Impact on vegetation

Hatton *et al*. (1999) recognise dependence of certain vegetation on groundwater. Though there is a lack of information on the interaction between vegetation and groundwater, it appears that the dependence of most vegetation on groundwater is low and that the role of the unsaturated zone is far more significant. Vegetation with high groundwater dependence is generally restricted to the riparian zone and areas adjacent to springs, areas with a shallow groundwater table and vegetation with deep rooting systems (Parsons, 2000).

Environmentalists often express concern about the impact of groundwater abstraction on the environment in general and vegetation in particular. Environmental impacts due to groundwater abstraction and lowering groundwater levels have been reported, but these tend to relate to specific geohydrological settings only. Direct negative impacts on vegetation have been claimed in some cases in South Africa (Scott and Le Maitre, 1998), but these remain subjective and unsubstantiated.

The impact of groundwater abstraction on vegetation seldom receives attention. It is possible that the lack of appropriate research into this topic, together with the slow rate of realisation of any potential impact, is the main reasons why this has not been well-documented in South Africa before.

2.3.3.3 Land subsidence

The romantic city of Venice in Italy is an international tourist destination partly because of its unique waterways and canals. According to Davis and De Wiest (1966), over-abstraction of groundwater to supply the city with water for industrial purposes has resulted in significant changes in inter-granular pressures below ground level that have caused widespread land subsidence.

Similar but less dramatic instances of land subsidence due to over-abstraction of groundwater have occurred in Mexico City, London, Bangkok, the Texas Gulf Coast and the Santa Clara and San Joaquin valleys in California (Davis and De Wiest, 1966). Also, abstraction of groundwater in areas of dolomitic rock may induce sinkhole formation e.g. West Rand, Gauteng.

2.4 Water use

2.4.1 Water use in South Africa

Water use is usually defined and measured in terms of withdrawal or consumption – that which is taken or that which is used. Withdrawal refers to water extracted from surface bodies or groundwater sources, with consumption being that part of withdrawal that is ultimately used and removed from the immediate water environment whether by evaporation, transpiration, incorporation into a product or other consumption.

Conversely, return flow is the portion of withdrawal that is actually not consumed, but instead is returned to a surface or groundwater source from the point of use and becomes available again for further use (USEPA, 2004).

Water consumption varies by water use category. National patterns of water use indicate that in the year 2000, irrigated agriculture represented the largest demand for surface water withdrawal in South Africa (SSA, 2006) as shown in Figure 2.2 below.

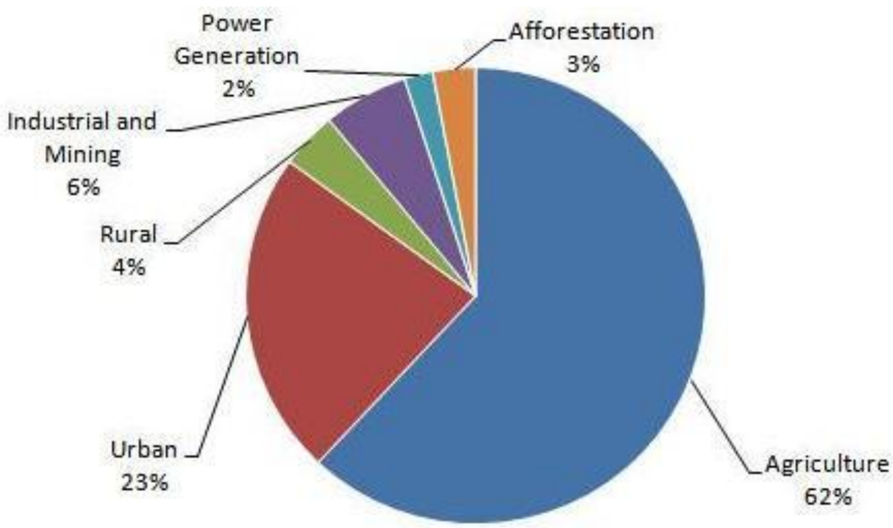

Figure 2.2: Water requirements by sector in South Africa

Source: SSA (2006)

Agricultural irrigation can be divided into crop irrigation and livestock watering. It is obvious that today this sector is still by far the largest single water user in South Africa. Agriculture and forestry combined consume approximately 65%, nearly two thirds, of the total available water resources in South Africa (see Figure 2.2). Agriculture therefore consumes a high percentage of water used, meaning less water available for return flow from such activities.

Urban water use contributes roughly 23% of the total surface water requirement of South Africa. This includes domestic water use, which is everyday residential use, and commercial water use, which is water used at all non-residential and non-industrial facilities. Rural areas typically consume much less water for domestic purposes than larger towns.

Water use of the industrial and mining sectors, estimated to be 6% of total surface water use, includes cooling in steel and other factories, washing and rinsing in manufacturing processes and dust suppression in mining activities. Power generation includes water used for the production of energy from fossil fuels, nuclear energy or geothermal energy and makes up 2% of the total water use which is a relatively small fraction compared to the other sectors. Most of the water withdrawn for thermoelectric power production is used for condenser and reactor cooling.

However, the continued growth in demand for water, compared to supply constraints and the likely decline in the availability of water due to climate change, is leading to an unsustainable situation. While it is to be expected that water consumption has to increase as the population and the economy grows, the current rate at which water use in South Africa is increasing far exceeds that growth rate.

Although the effect is mitigated by an increase in water use from both surface and groundwater sources for now, the amount of surplus water available for utilisation of any kind is declining fast, implying that water is becoming an ever more scarce resource. Future water use patterns will therefore have to adapt to changing climatic conditions and the water demand of other sectors to turn this trend around (Blignaut and Van Heerden, 2009).

2.4.2 Residential water use profile

Residential water use (or domestic water use) is one component of the complete urban water-use profile. Flack (1982) reports residential water use as the largest single category of urban water use in the USA, sometimes exceeding 75% of total urban demand. In an analysis of water use in the CCT, residential water consumers were found to contribute almost 90% towards the total number of water users and about 55% of the total water-use volume (Jacobs *et al*., 2007).

Water is used on a property by the consumer to meet various desired needs, some of which are for indoor demands and others to meet outdoor demands. Each of the individual water needs could be viewed as an "end-use" of water (Jacobs, 2008a). An "end-use" is considered the smallest identifiable use of water at a stand, as given by Jacobs and Haarhoff (2004a).

Water is fed to a property via pressurised water mains and a metered water connection, as depicted schematically in Figure 2.3 where "M" indicates the water meter and the dotted line is the property boundary. The potential end-uses are listed on the right and waste sinks (indoors or outdoors) shown on the left of Figure 2.3.

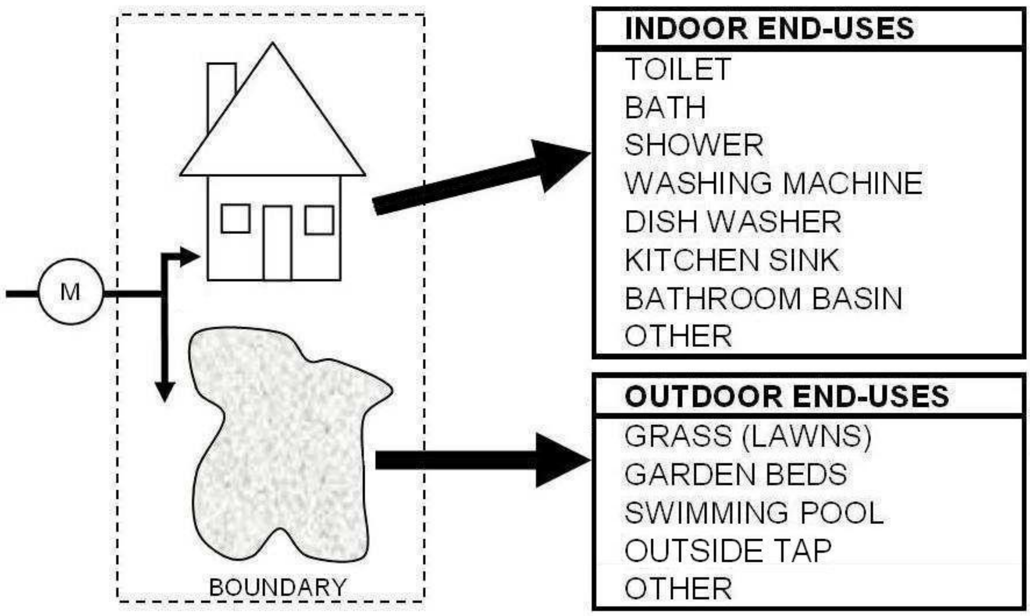

Figure 2.3: Schematic presentation of various end-uses at residential stands

Source: Jacobs and Haarhoff (2007)

The amount of water used indoors remains fairly constant throughout the year (USEPA, 2004). The bath, shower, toilet and washing machine represent the largest indoor end-uses in a typical suburban home and are also the ones most commonly reported on. In a comprehensive review of various international and local studies (Jacobs and Haarhoff, 2007) it was noted that the reported combined contribution of these end-uses was relatively constant, with an average contribution of 78% of the total indoor water use. This is in spite of great variability in terms of location and dwelling types of the studies reviewed.

Outdoor demand centres on garden irrigation, which contributes most to water demand at residential properties and is dependant mainly on the following factors (Jacobs *et al*., 2006):

- garden size (vegetation area);
- vegetation type;
- climate; and
- level of irrigation.

Garden size varies greatly from one dwelling to another and depends on stand size. It can also be expected that some consumers tend to irrigate their gardens regularly or even over-irrigate them, while others do not irrigate at all. These factors combined lead to great variability in garden water demand.

It is therefore clear that outdoor demand is hard to estimate. In separate studies by De Oreo *et al*. (1996) and Veck and Bill (2000) it was noted that dwellings, even in the same neighbourhood, may have significant variations in garden water demand. In the former study, water demand for garden irrigation is reported to contribute 78% on average to the total summer water demand. Garlipp (1978) also assessed the perceived portion of water use ascribed to garden irrigation at residential stands in Johannesburg and reported it to be an average of 73% of the total water consumption.

2.4.3 Domestic water usage in the Cape Metropolitan Area

According to DWAF (1992), the domestic sector is by far the highest consumer of water in the CMA utilising 59% of the total water consumption as shown in Figure 2.4. This is more than half the total volume of potable water used in the CMA, including unaccounted for water (UAW).

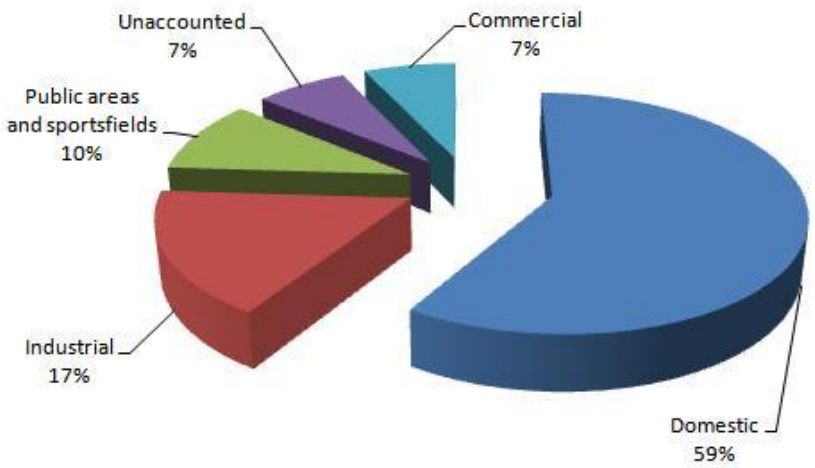

Figure 2.4: Water use per sector for the Cape Metropolitan Area

Source: DWAF (1992)

It is estimated that 35% of domestic consumption is used for garden irrigation purposes (DWAF, 1994), as depicted in Figure 2.5 below. Granger (1992) reported a slightly higher figure of water use for this sector, namely 50% of total residential consumption.

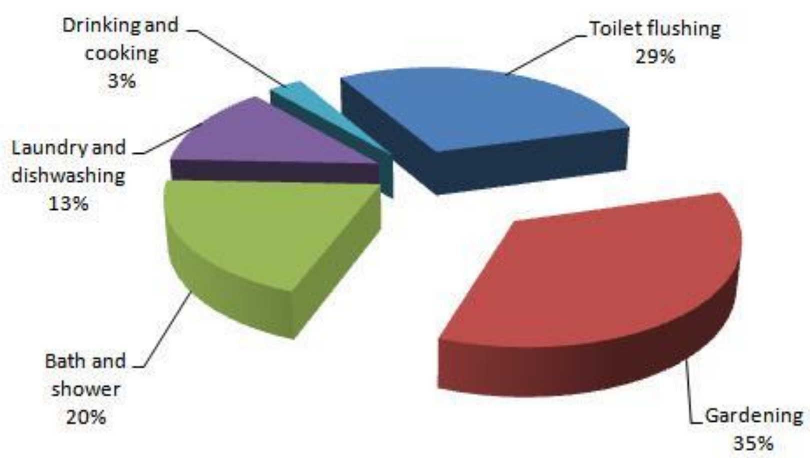

Figure 2.5: Domestic water use per sector for the Cape Metropolitan Area

Source: DWAF (1994)

This means that effectively between 20% and 30% of potable water supplied to all user-sectors in the CMA is used in the quest for green gardens at residential stands. Maclear (1995) estimated a similar figure of about 30% for this. Drinking and cooking, the only domestic water use for which potable water is considered absolutely essential, makes out less than 2% of the total water use of the CMA.

It is therefore clear from the figures above that ample water could potentially be saved in the domestic user-sector by substituting water used in sectors for which potable water is not essential with non-potable water, i.e. water from alternative sources such as groundwater, rainwater or greywater.

2.5 Residential water demand

Water demand is defined by Garlipp (1978) as the actual or estimated need for water for useful purposes. Residential water demand refers to the rate or quantity of water required for use at a residential stand, or group of residential stands, specifically. Estimation of water demand should ideally be based on metered records of actual water consumption. Alternatively, in the absence of accurate, measured data, suitable guidelines based on other parameters can be used to estimate water demand.

2.5.1 Water demand guidelines

A guideline or set of guidelines is a document approved and published by the relevant government institution(s) and extensively used by industry with the aim of guiding decisions and criteria in specific areas (Van Zyl *et al*., 2008). One such area that requires guidance in decision making is the estimation of domestic water demand.

Guidelines for residential average annual water demand based on property size were introduced to the South African Civil Engineering fraternity by Lock (1960), with the most recent publication of such guidelines by Van Zyl *et al*. (2008). These guiding principles are commonly used by civil engineers to estimate the projected demand requirements (i.e. AADD) of an area under investigation. AADD forms the basis of calculations performed during the design and analysis of new and existing water and sewer distribution systems, pump stations and storage reservoirs.

The maximum flow, or peak flow, is often more critical than the AADD from a design point of view. During design the AADD is multiplied by various peak factors to attain the peak flow which is used in design calculations. Accurate estimation of AADD in the early stages of design processes is thus critical (Jacobs, 2008b), as it eventually impacts an authority's water and sewer infrastructure budget and expenditure.

The most commonly used South African design guideline for estimation of municipal water demand was first published in 1983, called the "Blue Book" (CSIR, 1983). The latest version of this document, published in 2003, is known as the "Red Book" (CSIR, 2003). The colour code for each book simply refers to the colour of the folder containing the guidelines. The average water demand guideline in the most recent publication of the "Red Book" has remained unchanged since the first publication of the original guideline in the "Blue Book" almost 30 years ago. The "Red Book" AADD guideline does not respect geographic location, but is still widely used in South Africa.

For domestic water-demand estimation in developed areas, the water demand for single residential stands is based on stand area, according to Figure 9.9 of the "Red Book" as shown in Figure 2.6 below.

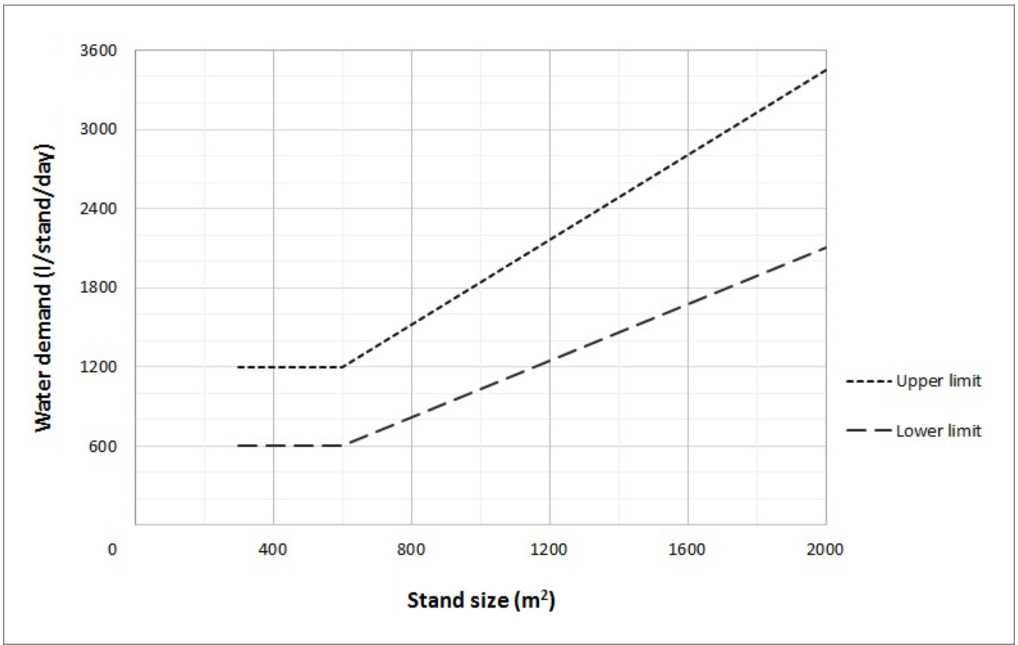

Figure 2.6: Annual average daily water demand for stands in developed areas

Source: CSIR (2003)

In this figure, an upper and a lower limit for domestic demand as a function of stand area (for erf sizes between 300 m^2 and 2 000 m^2) is given. The designer is expected to estimate the design demand somewhere between these limits and take into consideration factors such as average household size, income level, climate and cost of water in the area under consideration and to be serviced.

However, several past studies (Van Vuuren and Van Beek, 1997; Jacobs *et al*., 2004; Husselmann and Van Zyl, 2006) have reported the CSIR (2003) model, depending stand size, to be too conservative. As part of the outcome of these studies, updated and improved guidelines for estimating domestic water demand in South Africa were proposed by incorporating historical water consumption data and the most dominant factors influencing water demand.

2.5.2 Elasticity of residential water demand

Elasticity is defined as the sensitivity of a parameter such as water demand to a given factor or a set of factors. Various studies have been done on the elasticity of water demand with the most significant determinants as follows:

- price of water (Howe, 1967; Young, 1973; Gibbs, 1977; Agrhe, 1986; Espey *et al*., 1997; Veck and Bill, 2000; Van Zyl *et al*., 2003; Arbués *et al*., 2004);
- income (Cameron and Wright, 1990; Van Vuuren and Van Beek, 1997; Van Zyl *et al*., 2007);
- household size (Morgan, 1975; Garlipp, 1978; Danielson, 1979; Butler and Memon, 2006);
- stand size (Stephenson and Turner, 1996; Jacobs *et al*., 2004; Husselmann and Van Zyl, 2006; Van Zyl *et al*., 2008);
- system pressure (Gebhardt, 1975; McKenzie, 2001; Haarhoff *et al*., 2002; Lebaka, 2003);
- geographic location (Jacobs *et al*., 2004; Jacobs and Haarhoff, 2004b); and
- climate (Linaweaver *et al*., 1963; Kulik, 1993).

Although these variables are independent of each other, stand size and property value are frequently used as a surrogate for income, since more affluent areas often have larger stand sizes and since these parameters are easier to determine. According to Garlipp (1978), residential water consumption reflects an average increasing tendency with stand size.

It has been shown that household size (the number of people per household) is positively correlated to water demand (Danielson, 1979). However, household size, which has often been used to explain water demand in the past, has since been replaced by more accurate parameters. Nevertheless, household size was identified by Jacobs and Haarhoff (2004b) and Jacobs (2007) as being the most significant determinant of indoor water demand.

It has been shown by various studies (Veck and Bill, 2000; Van Zyl *et al*., 2003) that water demand has a negative price elasticity - in other words water demand decreases with an increase in price, although indoor water demand is generally accepted to be price inelastic (Jacobs *et al*., 2006).

System pressure differs for each system and has a significant impact on water demand. Reduced supply system pressure instantly reduces water consumption (Gebhardt, 1975) and leakages (McKenzie, 2001) which mean a reduction in water demand for the specific area where pressure is regulated.

Garden irrigation requirements depend on climatic factors that influence vegetation growth and that can vary significantly with geographic location. According to Linaweaver *et al*. (1963), the only two weather variables that influence water demand are temperature (i.e. evaporation) and rainfall. All published values for the rainfall elasticity of water demand are negative and for temperature all are positive (Jacobs *et al*., 2006). As can be expected, this implies that residential water demands reduce with higher rainfall and increase during higher temperatures, a direct result of garden water demand in both cases.

Some of the most relevant studies on the variables influencing water demand most are briefly discussed below.

2.5.2.1 Household size (Garlipp, 1978)

A study by Garlipp (1978) was one of the earliest of its kind in South Africa. Household size was found to be the most significant parameter influencing domestic water demand, with water consumption per capita decreasing with an increase in household size. The study concluded that water consumption on residential stands increases with stand size, income and household size.

A limitation of the study was, however, the inadequate and biased social surveys that formed part of it and which distinguished between the different racial groups of the country's population at the time.

2.5.2.2 Stand size (Stephenson and Turner, 1996)

Work by Stephenson and Turner (1996) investigating users of different income groups and their water use patterns in the Gauteng area provides valuable insight into water demand. The study confirmed the "Blue Book" guideline – that stand area exerted the most influence on domestic water consumption.

Other parameters that were found in this study to influence water demand included income, population density, water supply level of service and housing type. The use of an average stand size for all stands in each area that formed part of the analysis can, however, lead to misinterpretation of stand size.

2.5.2.3 Income (Van Vuuren and Van Beek, 1997)

Van Vuuren and Van Beek (1997) conducted a study on domestic and non-domestic water consumption in the Pretoria vicinity that confirmed a strong correlation between domestic consumption and household income. Water consumption patterns of high-income households were found to be more sensitive to climate (rainfall and temperature) than middle- and low-income households. This can be ascribed primarily to the high outdoor water demand of high-income households, which is generally associated with larger stands, typically with large irrigated gardens.

Compared to the "Red Book" guideline, it was found that the domestic AADD for all income categories in the study area was lower than that suggested by the guidelines.

2.5.2.4 Price of water (Van Zyl *et al*., 2003)

Van Zyl *et al*. (2003) investigated the elasticity of water price, system pressure, household income and stand area for residential water consumption in some Gauteng suburbs. The study grouped different end-uses into indoor consumption, outdoor use and leakage, and provides ranges of elasticity values identified for each modelling parameter.

The potential effects of these elasticity values on water consumption were then evaluated through a sensitivity analysis. Price was found to exert the most significant impact on domestic water consumption patterns. Household income, stand area and water pressure also showed positive demand elasticities.

The merit of this study lies in the fact that typical South African conditions with regard to both suburban and township developments were investigated. Potential parameters such as climate and geographic location were not considered in the analysis.

2.5.3 Stand size as single variable influencing water demand

A guideline for demand estimation based on a sole explanatory variable - a model with one independent factor - is termed a single coefficient model. Stand size, as single explanatory variable, has been used to estimate residential water demand in South Africa since at least the mid-1970s when the Transvaal Provincial Administration (TPA) recommended guidelines for the provision of essential services to residential townships (TPA, 1976). The original AADD guideline curve published in the "Blue Book" appears to stem from the earlier work done by the TPA.

A strong relationship exists between AADD and stand size (Jacobs *et al*., 2004). Literature indicates that the stand size elasticity of water demand varies significantly, but that the value is always positive. Estimates of domestic water demand are therefore still mostly based on stand area (CSIR, 2003; Jacobs *et al*., 2004; Husselmann and Van Zyl, 2006; Van Zyl *et al*., 2008).

It has been recognised that domestic water-demand estimates should preferably be based on actual water consumption of the area under investigation, i.e. analysis of measured data in municipal treasury. However, due to a lack of readily available data and more accurate methods often not being affordable, guidelines for the estimation of water demand based on stand size are still widely used and promoted today (Austin, 1995).

Some fairly recent studies on the elasticity of stand size as single explanatory variable to estimate water demand are summarised here.

2.5.3.1 Jacobs *et al*. (2004)

The study by Jacobs *et al*. (2004) presents a valuable discussion with regard to estimating residential water demand in Southern Africa using a single-coefficient model that relates water demand to stand area. The measured water consumption and stand size of more than 600 000 single residential stands from various municipal treasury data bases across Gauteng and the Western Cape were obtained and analysed in detail. Subsequently, new guidelines were proposed for residential water-demand estimation based on the water use of domestic consumers for which at least 12 months' data were available. This was the main outcome of the study.

Stand size was used in this model as single explanatory variable. Unique models for different rainfall and geographic (inland and coastal) regions in South Africa were presented with corresponding envelope curves to respect the influence of other variables. The AADD of stands in exceptionally affluent suburbs follows the upper boundary of the envelope curves, while that of less prosperous areas is represented by the lower envelope.

The authors concluded that the "Red Book" AADD guideline is conservative and proposed that the results of this study form the base for estimating the water demand of single residential stands in future. The guideline does not make provision for UAW, which must be estimated separately and added to the guideline AADD values.

2.5.3.2 Husselmann and Van Zyl (2006)

Husselmann and Van Zyl (2006) investigated the independent effects of stand area and income (using stand value as a surrogate for income) on water consumption, based on the measured AADD of approximately 195 000 domestic users in the Tshwane and Ekurhuleni metropolitan areas. The study found that there is a definite trend of increasing water demand with increases in both stand size and stand value.

The authors reported a strong link between water consumption and income, but found that stand value is too variable to be used as a parameter in design guidelines. Hence, it was concluded that stand size provides the best basis for the estimation of domestic water demand.

The study was limited to residential users with stand sizes between 200 m^2 and 1 400 m^2. A comparison of the results with the “Red Book” AADD guideline showed that the “Red Book” guideline curve underestimates the AADD for smaller stand sizes (300 m^2 to 700 m^2 range) and is too conservative for stand sizes larger than approximately 700 m^2. New guideline curves were proposed with this study, but it is important to note that these AADD values also do not provide for water losses.

2.5.3.3 Van Zyl *et al*. (2008)

The study by Van Zyl *et al*. (2008) is specific to South Africa and reports on an investigation of metered records spanning a period of at least 12 months. An initial data base comprising more than 2.5 million metered water consumption records extracted from 48 municipal treasury data bases across the country was analysed. The final amalgamated data set comprised 1 091 685 consumer records, following upon a rigorous cleaning and filtering process.

Single variable and stepwise multiple variable regression analyses were then applied to examine all the records in the final data set. This work is considered to be an improvement over that of Jacobs *et al*. (2004), since more data points were utilised and because several variables influencing domestic water consumption, apart from stand area, were considered in the analysis.

The results of this study confirmed that stand area is the most dominant parameter influencing domestic water consumption. Stand value (as a proxy for household income) and geographic location (inland and coastal) were also found to have a significant impact. Both stand size and stand value were positively correlated with domestic water consumption. However, it is not possible to have a consistent basis for predicting stand values due to constant fluctuations in property value, which leaves stand size as the best descriptor of AADD.

According to this study, only 53% of the suburb averages fall within the envelope between the lower and upper guideline curves of the "Red Book", which gave the strongest indication yet of the need for this commonly used guideline to be revised. Based on the metered records, a logarithmic regression model was generated as this gave the best fit to the data. Figure 2.7 shows the suburb averages and regression model plotted against the "Red Book" guideline.

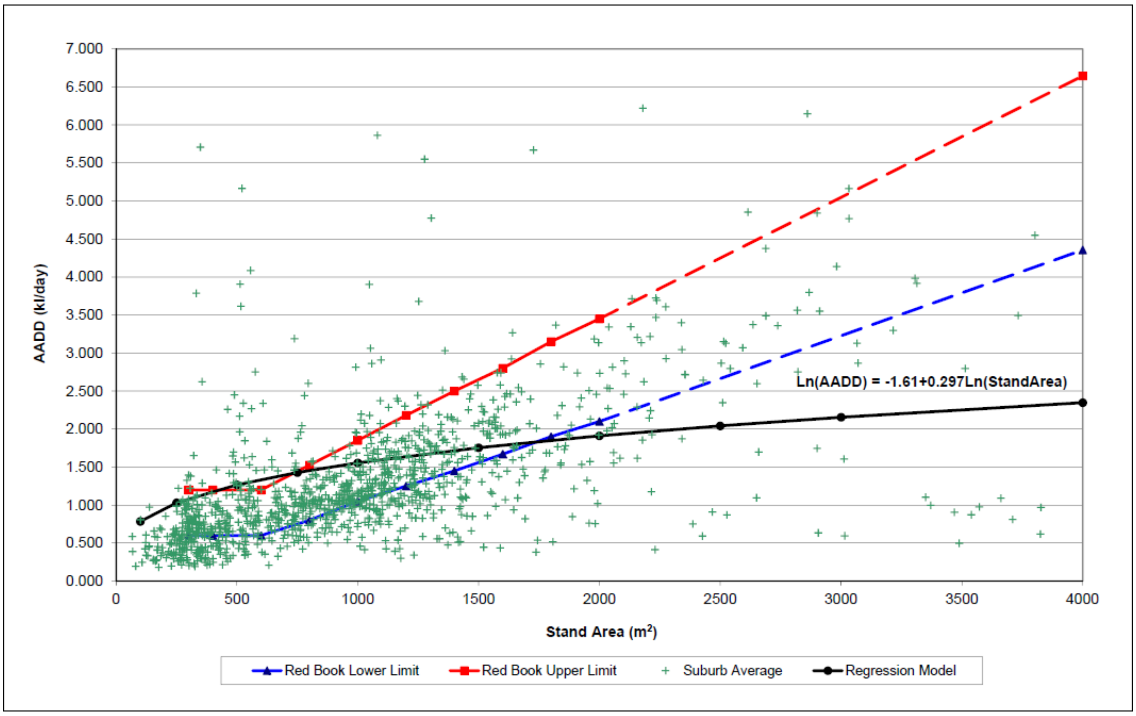

Figure 2.7: Assessment of the "Red Book" guideline using suburb AADD versus average suburb stand area

Source: Van Zyl *et al*. (2008)

The "Red Book" guideline curves were extrapolated up to 4 000 m^2 stand area. The regression curve falls within the "Red Book" guideline envelope for stand areas up to approximately 1 700 m^2, with the regression line very close to the upper limit for stand areas smaller than 750 m^2. The model predicts slightly higher AADD values for stand areas between 500 m^2 and 750 m^2 and lower AADD values for stand areas larger than 1 700 m^2. As a result, a new guideline curve with various confidence limits was presented to assist with the estimation of domestic water demand in South Africa based on stand area.

2.6 Private groundwater use

2.6.1 Legal aspects with regards to private groundwater use

The legal status of the private use of on-site water resources is not well delineated and infrequently discussed, which often makes it a contentious issue (Jacobs *et al*., 2011). According to the old South African Water Act (Act No.54 of 1956), "underground" water was distinct from "subterranean" water. This meant that groundwater was previously regarded as a private resource and ownership vested in the land owner. It was considered as "public property" only in 17 subterranean government water control areas.

Research on international water by-laws is dominated by a provision declaring all groundwater to be state or publically owned water. In the former Soviet Union water was an exclusive state asset and was made available only for use. It could neither be bought nor sold and could therefore not be separated from the state property (Langton and Raymer, 1994).

The status of all water resources in South Africa averted to "public property" (with the minister acting as public trustee) after the promulgation of the NWA in 1998. The main objective of the NWA is to make provision for the management of water resources through relevant structures. Of specific interest to the household user is what is considered as permissible use and the procedure associated with this use.

In section 21 of the NWA it is stated that, among other things, the "taking of water from a resource", constitutes a water use. In general terms a licence is required for any water use and the procedures are dealt with in the NWA. The NWA simultaneously also empowered the Minister in section 26 to make regulations to enforce the registration of all water uses. These regulations (Regulation 1352 published in Government Gazette No. 20606, 12 November 1999) were issued, and effectively require the registration of all water use activities within a specific time frame.

The only water uses that are exempt from the registration process are provided in section 10 of the regulations which includes the following:

- Schedule 1 use;
- if not required in terms of a general authorisation issued; and
- if water is obtained from a bulk water supplier or other management structure.

There are, however, a number of situations where water can be used without a licence as stipulated in section 22 of the NWA as follows:

"A person may only use water -

(a) without a license -

(i) if that water use is permissible under Schedule 1;

(ii) if that water use is permissible as a continuation of an existing lawful use; or

(iii) if that water use is permissible in terms of a general authorisation issued under section 39."

With reference to section 22 above, Schedule 1 water is defined in the NWA as water made available a user who is allowed to:

(a) take water for reasonable domestic use in that person's household, directly from any water resource to which that person has lawful access;

(b) take water for use on land owned or occupied by that person, for -

(i) reasonable domestic use;

(ii) small gardening not for commercial purposes; and

(iii) the watering of animals (excluding feedlots) which graze on that land within the grazing capacity of that land, from any water resource which is situated on or forms a boundary of that land, if the use is not excessive in relation to the capacity of the water resource and the needs of other users.

(c) store and use run-off water from a roof.

Therefore most household water uses could be considered to fall within these categories. Although DWAF is aware of increased private groundwater abstraction at household level (Colvin and Saayman, 2006), this water is covered under Schedule 1 of the NWA. Groundwater from boreholes and wellpoints for domestic purposes may therefore be abstracted and used without the requirement of a licence or registration thereof.

However, a municipality may still regulate or enforce registration of such water use in its area of jurisdiction by formulating local by-laws or regulations that override the entitlements under Schedule 1 of the NWA. No such by-laws or regulations have been promulgated either by DWAF or CCT to date.

Hence in summary (Jacobs *et al*., 2011):

- the use of groundwater for domestic purposes by any individual home owner in a serviced area could be deemed "legal" in the general case and no registration of the particular use is required, unless
- a municipality has followed the necessary procedures by which by-laws have been put in place, thus regulating the registration of such use - in which case a home owner may be required to register, with consequences if not registered.

2.6.2 The impact of personal on-site water resources

A personal on-site water resource, conveniently described by the acronym POSWAR, is an alternative water source to piped municipal supply. POSWARs are privately owned sources on residential properties which are installed, managed, operated and maintained by the home owner or occupant. The commissioning and application of POSWARs by private home owners is often drought-driven, but is available to all residential consumers in South Africa (Jacobs, 2010). The most common alternative sources include groundwater abstraction, rainwater harvesting and greywater re-use.

Garlipp (1978) recognised that alternative water sources are used at some stands in conjunction with municipal supply. This is mainly applied to meet end-use needs where water quality issues are not a concern, in other words for non-potable purposes in and around the home. For this reason the most common application of POSWARs is for garden irrigation, which could explain some of the variation in demand for larger residential stands (Jacobs *et al*., 2004). Toilet flushing is considered to be the only indoor application of POSWARs, since potable water is really needed for most other end-uses inside a home.

According to Jacobs (2010), the yield from a typical GAP is considered to be relatively high compared to the water demand of residential properties. Private GAPs typically meet all garden irrigation demand, while rainwater harvesting and greywater re-use systems produce notably less water than groundwater sources.

The application of POSWARs by consumers in residential areas impacts on the piped water distribution system (WDS). Until about 1983, the quantity of water abstracted from private boreholes in urban areas of South Africa was considered insignificant in comparison with that from municipal water supply (DWAF, 1986). However, broad and extensive use of POSWARs in residential areas indirectly creates an apparent load reduction on piped reticulation systems which could realistically lower the average water demand of a specific residential area. If managed properly this can be an advantage, since POSWARs could be seen as a way to reduce the load on the municipal WDS and thus a means to “manage demand” on the system.

Previous research has shown that garden irrigation is largely responsible for the peaks in WDSs (Dietemann, 1998). In other words, the supply of water for garden irrigation from POSWAR sources would lead to a direct reduction in peak flows in WDSs. In contrast to being viewed as a potential WDM measure, such use could be a concern in cases where empirically derived design guidelines for estimating water demand are based on analyses of data from consumer water meters, and are thus not accurately reflecting the true water needs of residential stands.

Various recent publications presenting guidelines for estimating demand are founded on historical records of water consumption (Jacobs *et al*., 2004; Husselmann and Van Zyl, 2006; Van Zyl *et al*., 2008). Based on these guidelines - where POSWARs are possibly applied at many of the stands which contributed to the water consumption figures used to derive it – entire WDSs may have been designed without really allowing for the “complete water needs” of the relevant group of consumers.

At some point in time, if a certain POSWAR source were to fail, the consumers relying on it may suddenly turn to supply from the WDS to meet these needs, resulting in an unforeseen overload and insufficient pressure at critical points in the WDS. Hence the purpose of this study is to contribute to the better understanding and estimation of the impact of private groundwater use - the most commonly applied POSWAR - on potable water demand and the ultimate incorporation thereof when deriving water demand guidelines in future.

2.6.3 The appeal of private GAPs

The possession of private boreholes in South African cities may be traced back to the days when the majority of the population were still farmers and the possession of one’s own source of water was customary (Garlipp, 1978). The idyllic vision of an old house with a windpump in the backyard, set in a small Karoo town, comes to mind.

Nowadays though, farms are situated on the outskirts of cities as well as in rural areas, as farming activities have become largely commercial. However, people still grow private gardens at home, many of which are extensive in size and with a relatively high irrigation demand.

According to Gebhardt (1975), garden watering requirements depend to a large extent on the rate of evapotranspiration, which varies greatly for different geographic locations. Plants' water requirements also vary significantly from one genotype to another (Jacobs *et al*., 2006).

The hot and dry weather during summer months in the Western Cape, accompanied by a high rate of evapotranspiration and an absence of rain, means that water demand for irrigation purposes increases rapidly in this time. This is in direct contrast with the main aim of water restrictions, which primarily target outdoor water use and, more specifically, garden irrigation. Many Cape Town residents had wellpoints or boreholes installed on their properties during the restrictions, enabling them to use this source for irrigation (Colvin and Saayman, 2006). Much publicity was given to this in the local press at the time with headlines such as "Tapping the hidden reserves for our thirsty city" or "Wellpoints and boreholes can be a lifeline for parched gardens".

When groundwater is used at a metered stand, water supply from the municipal system is, in effect, replaced by a GAP to meet the consumer's water demand (or part thereof), regardless of what it is used for. Therefore, given that water is merely abstracted from an alternative water source in such cases, it could be argued from an environmental viewpoint that water is not actually "saved", since the efficiency of use does not improve. However in this context any reduction in a consumer's metered water use is deemed to be a "saving".

Any physical saving in the metered use at a stand is reflected on the consumer's water bill. This is coupled with a smaller sewerage tariff being billed as a percentage of the total metered water use. As part of a study by Colvin and Saayman (2006), a survey was conducted on residents using groundwater and their motive for this use. The most common reason given by respondents was to save on their monthly water account, which further substantiates the aforementioned statement.

The additional electricity cost for the operation of a private GAP is insignificant considering the saving it facilitates. Most wellpoints and boreholes are equipped with small centrifugal pumps ranging between 0.5 kW and 1 kW in size – a pump with a

1 kW motor uses 1 kW per hour which equals 1 unit of electricity. This type of pump is extremely economical to operate, similar to the relatively low running cost of most swimming pool pumps, for example. However, in terms of costs, the private use of groundwater is driven by the price (i.e. cost) of water from municipal supply versus that of electricity.

Although capital expenditure is required to purchase a pump and cover installation costs, the potential savings that may arise from it is far greater, which actually renders the initial spending an investment. As said by Fourie (2012), "a wellpoint or borehole is a definite asset to any property, whether residential or non-residential, and will be marketed as an extra to any property that is for sale, similar to a swimming pool or solar heating system for example".

The use of "garden boreholes" therefore provides many advantages and offers a real financial benefit when actively used as substitute for water from municipal supply - especially at residential stands with large gardens, as private GAPs are utilised primarily for irrigation.

2.6.4 Applications of groundwater at serviced residential stands

Groundwater use for domestic purposes is common in South Africa. GAPs are installed on the premises of many residential stands, but are considered to be limited to high-income (or at least medium-income) low-density properties (Jacobs, 2010). They are operated privately by the owners or occupiers of such properties - in some cases a single GAP serving a group of neighbouring erven.

Residential abstraction of groundwater in the Western Cape is fairly common and is mainly used as a supplementary water source. A single GAP on a residential stand could easily supply the entire water demand (AADD) for a property based on the most recent empirical guidelines for the estimation of AADD. However, due to plumbing complexities and water quality concerns, groundwater is commonly used exclusively to meet outdoor needs only, mainly garden irrigation (Jacobs, 2010).

Wellpoint yields are sufficient for the watering of small to medium sized gardens. The installation of boreholes for irrigation purposes in areas unsuitable for the sinking of wellpoints is likely to be considered only for grassed sports fields, parks, golf courses and high-income households with large and well-watered gardens (CCT, 2001b). This is due to the much higher installation costs associated with boreholes compared to that of wellpoints. Even so, it is apparent that, at residential stands, groundwater is used primarily for irrigation and gardening purposes.

In a study by Colvin and Saayman (2006) on the private use of groundwater at serviced residential stands in Cape Town it was found that this source is used predominantly for garden irrigation as illustrated in Figure 2.8.

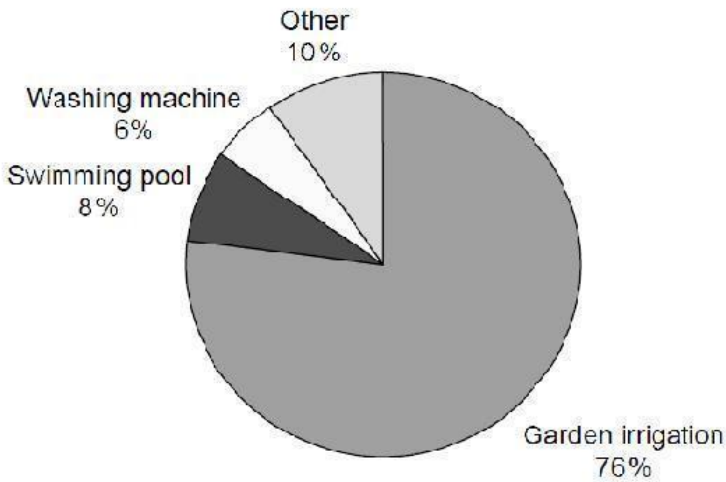

Figure 2.8: Residential groundwater use in Cape Town

Source: Colvin and Saayman (2006)

Groundwater is also often used for maintenance purposes, such as pressure-cleaning of roofs, driveways, paving and other surfaces (Wright and Jacobs, 2010) in areas where iron staining from groundwater does not occur. However, as evident from the state and colour of the walls of some houses in certain suburbs of the Cape Peninsula, for many residents this effect is no drawback.

As with all schemes, there are advantages but also disadvantages that go with the use of GAPs. These are summarised in Table 2.4 presented hereafter.

Table 2.4: Advantages and disadvantages of “garden borehole” use

Advantages	Disadvantages
Savings in potable water requirements	Initial capital layout
Long term financial benefit	Possible soil subsidence
Control water table fluctuations	Possible impact on wetland systems
Devolution of maintenance from service provider	Possible long term degradation of water quality from possible saline intrusion
Research and development opportunities	More groundwater protection and pollution prevention required
Job creation/opportunities	Potential health risks to humans *
Aid to relieve strain on natural environment *	Drop in groundwater levels due to over-abstraction *
Add value to property *	Iron staining in certain areas *

* Additional items added by author as deemed applicable

Source: Saayman and Adams (2001)

The advantages of “garden boreholes”, however, far exceed the likely disadvantages and risks posed directly to the owner and property. The potential financial benefits to be reaped from the operation of private GAPs at residential stands are notable.

2.6.5 “Life expectancy” of boreholes and wellpoints

In a study by Jacobs (2010) it was concluded that once a POSWAR has been installed and is being used, it typically remains in use long after the “need” for it (say that arose during a period of drought or water restrictions) has passed. This seems valid for all parts of South Africa and all social classes of residential users.

Private GAPs are deemed a reliable alternate water source (mainly for irrigation) by many residents in the Cape Peninsula – that is if functioning. The operational state of boreholes and wellpoints depends primarily on the following two factors:

- level of water table i.e. groundwater level must be higher than the slotted casing of borehole or wellpoint; and
- pump lifting groundwater from below the water table to ground level must be in working condition.

These are the primary requirements for a borehole or wellpoint to be operative. Other elements, such as the quality of groundwater being abstracted, plumbing complexities above ground, uninterrupted power supply to operate the pump and willingness of an owner or resident to utilise the specific GAP, are secondary to the primary factors listed above.

However the level of groundwater cannot be controlled by the GAP user. It is directly dependent on the amount of rainfall during the previous (or current) rainy season and, to a lesser degree, the amount of groundwater abstracted in the surrounding area. This leaves "regular pump maintenance" as the only essential aspect the user has to manage in order to ensure the GAP is operative and capable of being used.

The centrifugal pumps which are most often connected to boreholes and wellpoints are self-priming and designed for long, continuous operation with minimal servicing required, resulting in low maintenance and relevant costs (Maclear, 1995). This, however, depends on the make of the pump and the frequency of use.

My father can personally testify to such durability (Wright, 2012). He lives in Oakdale, Bellville and had a wellpoint installed at his home towards the end of 1989, shortly after we moved to Cape Town. The wellpoint pump, still the very same one originally installed and that has been used extensively since then, was serviced for the first time in more than 22 years earlier this year. The service basically entailed replacement of the pump seal and bearings only.

Moreover, one of the private residential GAPs registered during the recent CCT registration process (GAP registration no. 7 185 at a house in Langeberg Heights, Durbanville) has been in use since 1964, i.e. almost 50 years. This is supported by Cilliers (2011), a local wellpoint installer who has been installing wellpoints mainly in the northern suburbs of the CMA for more than 30 years and considers this not an unusual occurrence.

Cilliers (2011) also confirmed that he "has not had any comebacks on wellpoints he installed during this time other than problems related to wellpoints that "dry up" in summer months and dry periods or a lack of pump maintenance by the owner". It is clear that these problems have to do with the primary requirements for GAPs to remain operative not being satisfied.

No further surveys were done to verify stands registered during the CCT registration process or to identify any other stands where private GAPs are utilised. However a few registered residential stands in the Bellville, Kuilsrivier and Brackenfell areas were randomly selected to participate in a small-scale door-to-door census to confirm whether the private GAPs located at these particular stands were still operative and actively used. The survey was done orally, on the spot and did not include any forms that had to be filled in by participants.

The areas where the census was carried out are situated in the northern suburbs of Cape Town. These were chosen purely because many registered stands are located in these areas and are close to the neighbourhood where I live. The response was good, although stands approached where an adult residing permanently at the address was not home at the time were not visited again and were excluded from the survey.

The feedback was positive at those stands where an adult resident was present and confirmed that all the on-site GAPs at the properties surveyed were still being used. The feedback of the door-to-door survey is summarised in Table 2.5 below.

Table 2.5: Summary of feedback from door-to-door survey

Suburb	**Number of erven approached during survey ***	**Number of erven actually surveyed (adult at home)**	**Number of erven with CCT registration sign or other poster displayed outside property ****	**Number of erven with visible iron stains on walls and other surfaces**	**Private GAP still operative and regularly used**
Oakdale, Bellville	12	10	4	4	10
Soneike, Kuilsrivier	15	13	7	9	13
Protea Heights, Brackenfell	16	11	5	6	11
Total	**43**	**34**	**16**	**19**	**34**

* All stands approached during survey including those with no adult resident at home

** Refer to the official CCT registration sign or other posters that residents display in front of their properties to state that groundwater is being used for irrigation purposes

Though this survey was applied on a very small and limited scale, the outcome of it goes a long way in supporting the claim that, due to the mostly trouble-free operation of “garden boreholes” and the financial benefit they provide, they continue to be used long beyond their installation and also after the recent water restrictions in the CCT were lifted.

2.7 The unique case of the Cape Peninsula

2.7.1 The Cape Flats aquifer

The greater CMA lies on one of the most extensive sand aquifers in South Africa, known as the Cape Flats Aquifer Unit (CFAU), with a highly significant groundwater supply potential (Maclear, 1995). The CFAU is an unconfined aquifer (Tredoux, 1984) and has, on numerous occasions, been identified as a viable source of water supply for the CMA (CCT, 2001b). According to Colvin and Saayman (2006) it has the highest probability of secured supply with typically high yields.

The topographic low of the CMA, located between Table Mountain and the Drakenstein and Hottentots Holland mountains, is commonly known as the Cape Flats. Rainfall over the Cape Flats is much less than in the surrounding mountains and the average rainfall recorded at various stations in this area ranges between 500 and 700 mm per annum (Tredoux, 1984), with most of the rainfall occurring during winter months.

The CFAU consists of Cenozoic deposits underlain by a secondary rock aquifer of essentially impervious Malmesbury shales and Cape granite. Sedimentation initially occurred in a shallow marine environment, subsequently progressing to intermediate beach and wind-blown deposits, and finally to aeolian and marsh conditions. A feature of the sediments is the presence of shelly material over most of the area. The sand body is generally stratified horizontally and several lithostratigraphic units can be recognised (Wright and Conrad, 1995).

The simplified geology of the Cape Peninsula is shown in Figure 2.9 below. The areas of quaternary sands correspond well with the extent of the CFAU, which is bordered by other geology and the southern and western coastlines.

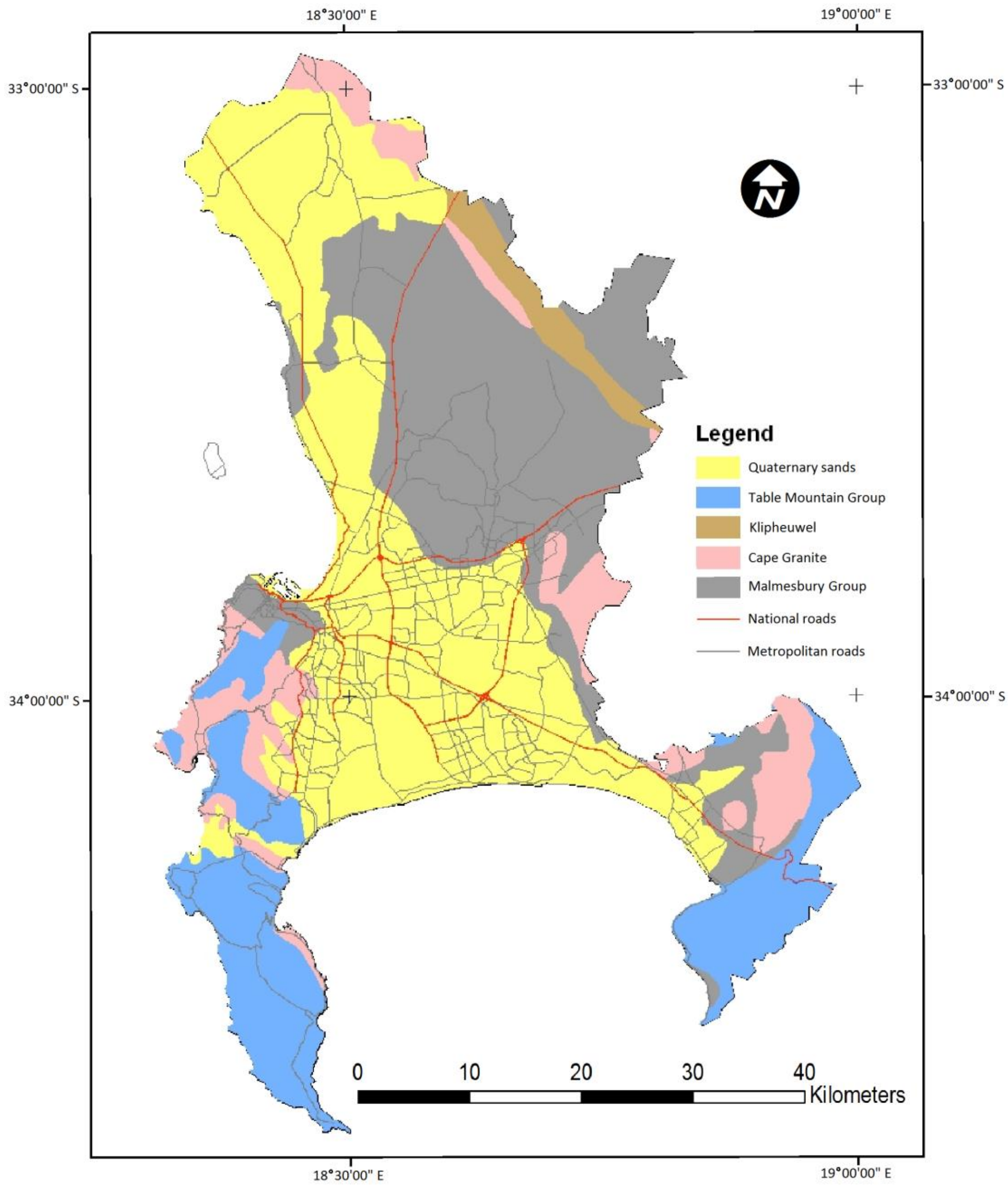

Figure 2.9: Simplified geology of the Cape Peninsula

Source: CG (2013)

Thick unconsolidated silica sand deposits underlie most of the Cape Flats from False Bay in the south to Table Bay in the north and also occur along a narrow strip from Muizenberg to Noordhoek, around Kraaifontein and in the Strand area. The alluvial sands extend in a northerly direction pass the town of Atlantis and along the West Coast as shown in Figure 2.10 below.

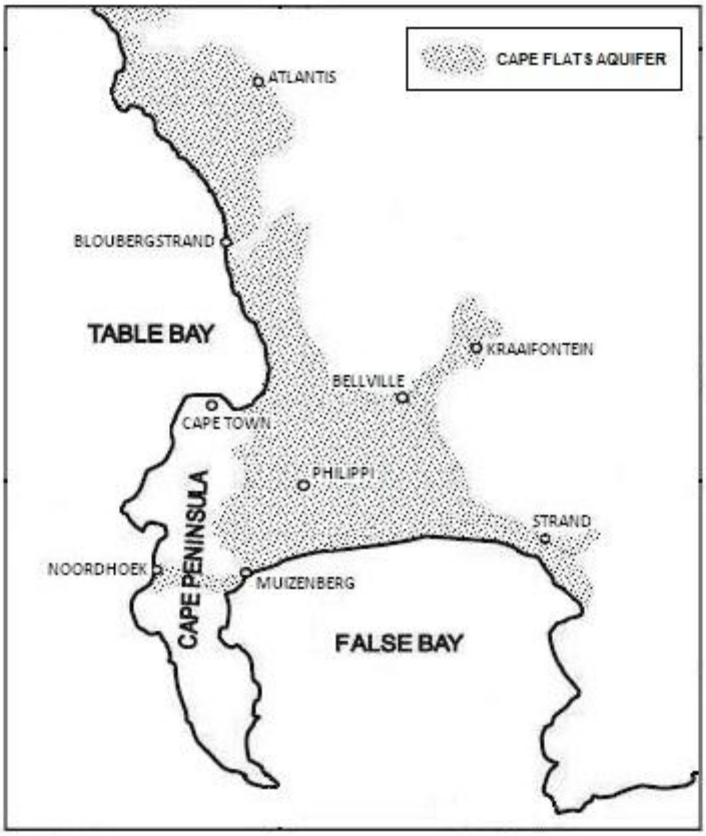

Figure 2.10: Regional extent of the Cape Flats Aquifer Unit

Source: Adelana *et al*. (2010)

The CFAU extends over an area of approximately 630 km^2 (Tredoux, 1984). According to Saayman and Adams (2001), the thickness of the Cape Flats aquifer deposits may reach 30 m in places, with a shallow water table, ranging from a few centimetres below ground surface in winter months to about 4 m in summer.

This, together with the fact that Cape Town receives winter rainfall, makes it an ideal candidate for groundwater abstraction during summer months to relieve stress on other water sources during the dry part of the year. With winter rains the levels in the CFAU should recover if the aquifer is not over exploited. By lowering water levels during abstraction in the summer season the storage capacity in the aquifer is also increased, which in turn reduces the risks of flooding in some of the low-lying parts of Cape Town (Saayman and Adams, 2001).

As a primary aquifer, the CFAU provides several distinct advantages, as given by Wright and Conrad (1995):

- recharge occurs naturally during winter months and serves as reliable resource during the long dry summer;
- artificial recharge is relatively easy and provides for increased resource potential and additional treatment of wastewater i.e. treated sewage effluent and urban run-off;
- low development and maintenance costs in comparison with surface water schemes;
- centrally situated with regard to the urban area; and
- supply of water from a groundwater scheme can be introduced or halted instantly, providing maximum management flexibility.

The quality of groundwater contained in the CFAU is excellent, apart from elevated levels of dissolved iron in the primary aquifer (Saayman and Adams, 2001). According to Maclear (1995) it is classified as fresh, which can be attributed to the high recharge rates. Natural groundwater recharge to the CFAU takes place during the winter rainy season (Tredoux, 1984), hence the cyclic patterns in groundwater levels. Recharge is estimated to vary between 13% and 30% of the annual precipitation (Fleischer and Eskes, 1992) - the higher figure of which coincides with areas of bare sand dunes.

With respect to salinity levels, most of the CMA underlain by the CFAU, as well as the Atlantis area, is suitable for wellpoint and borehole development intended for garden watering (CCT, 2001b). Maclear (1995) stated that the salinity of groundwater contained in the CFAU generally ranges between 300 – 1 000 mg/l TDS which falls within the limits for drinking water. However, the fact that the CFAU is unconfined, is recharged practically over the entire area and the water table is seldom far below ground level, render the aquifer particularly vulnerable to pollution (Tredoux, 1984).

The generally shallow water table and unconsolidated nature of the saturated sands of the CFAU result in a primary aquifer of significant exploitation potential that is ideal for wellpoint installation and operating conditions. A large number of home owners on the CFAU have capitalised on this situation and successfully use wellpoints for garden irrigation (Maclear, 1995). For groundwater to be abstracted from outside this area borehole drilling would in all likelihood be required.

Groundwater abstraction from the CFAU by means of GAPs is therefore a feasible method and source of alternate water supply for private use across the large parts of the CMA that yield sufficient quantities year-round for localised and small-scale use such as garden irrigation.

2.7.2 Recent water restrictions in the Cape Metropolitan Area

Water is a scarce resource in the Western Cape and historically there have been periods of water restrictions in the area to alleviate the pressure on available water supply sources (Frame and Killick, 2004). Water restrictions are an effective way to achieve reduced water consumption (from municipal supply) during times of critical water shortages and, furthermore, present an opportunity to increase public awareness of the need to use water more efficiently (CCT, 2001b).

During the past decade water restrictions have been implemented by the CCT on more than one occasion. Low-level water restrictions aimed at a 10% reduction in both urban and agricultural demands in the CMA, i.e. Level 1 water restrictions, were introduced on 1 November 2000. These restrictions were subsequently lifted in 2001 when the targeted water savings were achieved.

During the winter (rainy) season of 2004, the catchment areas of the main supply systems to the Cape Town area received a mere 56% of the average historical rainfall for this period. Subsequently the combined storage of all the reservoirs in the CCT system dropped to only 57% and on 1 February 2005 storage was about 20% lower than the storage at the same time the previous year (2004), which in turn was 20% lower than the year before that (2003).

The CCT administration responded proactively to this situation with an official notice calling for Level 2 water restrictions in accordance with the City's by-laws, effective from 1 January 2005. An awareness campaign was initiated on 1 October 2004, three months prior to this date. The restrictions, initially for a period of twelve months, set a target of achieving 20% saving in bulk water usage during this period. The fine for transgression of these restrictions was pegged at R 1 000 by the magistrate.

These restrictions primarily targeted outdoor water use and, more specifically, garden irrigation which is an end-use more common to properties with larger stand sizes. A 14% overall reduction in water demand was achieved during the summer period of these restrictions (compared to the same period the year before) with a clear trend of increased percentage saving with increased stand size (Jacobs *et al*., 2007).

The restrictions were intensified even further in January 2005 to limit garden watering to only one half-hour session per week. In response many Cape Town residents had wellpoints or boreholes installed on their property to use for garden irrigation (Colvin and Saayman, 2006) as the restrictions were limited to potable water usage only. The use of groundwater was therefore fully exempt from these restrictions which meant that free, unlimited use of private GAPs was allowed during this period.

According to Garlipp (1978) the private use of groundwater became more popular during times of water restrictions when those who could afford boreholes were not prepared to let their gardens succumb to drought. Ellis and Van Duuren (1974) reported that large numbers of residents in the more affluent eastern suburbs of Pretoria started to water gardens from boreholes during periods of imposed water restrictions, while Lomberg and Rosewarne (1996) also noted that new boreholes in Port Elizabeth were sunk primarily in response to drought conditions at the time. Similarly many boreholes were drilled in Perth, Australia for these purposes during the water restrictions of the late 1970s (Saayman and Adams, 2001).

In November 2005 the reigning Level 2 water restrictions were reduced to a Level 1 grading in preparation for the planned new CCT water by-laws. The city amalgamated all its water by-laws (from the previous municipalities of Tygerberg, Oostenberg, Helderberg, South Peninsula, Cape Town City and Blaauwberg, which were absorbed into a single metro to form the City of Cape Town in December 2000) into one water by-law for the entire CMA. This was promulgated in September 2006 and further amended in February 2011.

Schedule 1 of the CCT water-bylaws incorporates Level 1 water restrictions to form a permanent part of this legislation. The Level 1 restrictions of November 2005 were never lifted and the CCT in effect has remained in the 10% water tariff ever since. Provision is made in the water by-laws to implement more stern restrictions if the need arise which could be Level 2 or 3, i.e. 20% or 30% targeted savings, depending on the situation at the time.

According to Wilson (2012) the benefit of having Schedule 1 in the water by-laws is that it is now enforceable by law, whereas the previous water restrictions were not. Until the promulgation of the CCT water by-laws, water restrictions were punitive and basically considered as mere recommendations.

2.7.3 The City of Cape Town GAP registration process

The CCT water restrictions imposed at various times between 2000 and 2006 largely prohibited the use of municipal (potable) water for gardening and irrigation purposes. A detailed account of the water usage and savings during this specific period of water restrictions is given by Jacobs *et al*. (2007). Non-potable water users, however, were not compelled to comply with the water restrictions relating to watering times. This presented a tricky scenario to water inspectors tasked with enforcing the restrictions, as they could not necessarily tell from the onset whether the water used outdoors at properties being inspected was from municipal supply (prohibited) or other non-potable sources i.e. groundwater, rainwater or greywater (permitted).

This lead to the CCT's water and sanitation department initiating an extensive process across the city, the largest exercise of its sort conducted to date that could be found during this study, whereby the residents of all properties where non-potable water were being utilised were urged to register such use. In fact, the private use of alternate water sources during this period was only permitted at registered stands.

Previous research has indicated that many groundwater users were non-cooperative in this regard and did not voluntarily register private GAPs in Pretoria (Simpson, 1990) and in Port Elizabeth (Lomberg *et al*., 1996) during similar studies. Langton and Raymer (1994) reported, after poor public co-operation in a census to identify boreholes in suburbs of Port Elizabeth, that the reasons for this can be ascribed to a perceived threat of intervention by the local municipality and the ultimate control of private groundwater use. The same is considered to be true in the case of Cape Town, although this could not be confirmed and falls outside the scope of this study.

The request for the registration of boreholes and wellpoints by an individual within a municipal area is not dealt with directly in the NWA. However, it could be regulated by the specific municipality through the introduction of appropriate by-laws.

The registration of an existing water use is compulsory in terms of section 151 (1) (g) of the NWA, stating that:

(1) No person may -

(g) fail to register an existing lawful water use when required by a responsible authority to do so;

The process and call for the registration of such activities in the CCT was widely advertised and requested in local media and newspapers, posted on public notice boards at municipal offices, communicated to property owners on their monthly utility bills and to residents through pamphlets distributed in certain suburbs and post office boxes. It was iterated that with this process the specific stands were being registered, and not the property owners or occupiers themselves (Wright and Jacobs, 2010).

The registration forms used and the information requested on them varied for the different local municipalities. Wright and Jacobs (2010) reported that some types of form required comprehensive information about the owner or resident, the stand and specific source being registered (including name and surname, full street address, plot number, suburb or town, contact number, type of alternate water source and, in the case of groundwater, the type of structure i.e. borehole, wellpoint or open well, period in use and average yield) whilst on others only the name of the owner and address of the particular property had to be supplied.

According to Sims (2011) the specific erven were registered and not the property owners or occupiers themselves. "It was not a billing or revenue exercise and owners or occupiers were not billed for the ownership of a borehole or wellpoint or the water usage from it." Participants had to register at their local municipal office. The CCT also conducted a door-to-door survey in certain suburbs where the use of boreholes or wellpoints was widely observed and expected. This provided those who failed to register voluntarily during the first round with another opportunity to register.

A unique registration number was allocated to every stand registered against its plot number or address. Residents who registered also received a free weather-proof sign which had to be placed at a position clearly visible from the outside of the registered property to indicate that a borehole or wellpoint was present and actively used (Sims, 2011). An example of the sign is shown in Figure 2.11 below.

Figure 2.11: Example of CCT registration sign

Identical signs, all furnished with the words "borehole water", some with colour blue in place of red but each with its own unique registration number, were used for all stands being registered. However, these signs were issued not only for the registration of private boreholes, but also for wellpoints and other sources such as rainwater and greywater that were registered.

The sign was therefore an indication that non-potable water from some source, not necessarily groundwater or a borehole specifically, was used at properties where it was displayed and that the specific stand was registered for this. It also enabled the owners and occupiers of such stands to use this water freely during non-watering times when garden irrigation with municipal water was prohibited.

Many residents across the Peninsula did not register the non-potable water sources used at their premises during this process and instead put up their own homemade posters to indicate that the water used for irrigation (outside the scheduled watering times) was not from municipal supply. Others chose to display the sign supplied by the company that installed their borehole or wellpoint to serve this purpose. It is understood that such stands were let off the hook and basically allowed by the CCT to carry on without receiving a warning or being fined.

The absolute majority of registered stands were registered between the end of 2004 and 2005 which coincided with the period of Level 2 water restrictions in the CMA. The registration process was eventually abandoned in mid-2006, when the CCT water by-laws were promulgated. However, according to Sims (2011), “the information gathered during this registration process provided immense environmental monitoring and research value, which convinced the CCT to resume it” towards the end of 2011. It must be noted that no data from the latest survey was yet available at the time when this study was concluded.

No further information was available on whether the GAPs registered during the previous CCT registration process until 2006 were still operational at the time of this study, apart from the small-scale survey conducted in certain suburbs to confirm the active usage of GAPs registered at these stands.

Therefore, for the purposes of this study and given the reported longevity and durability of boreholes and wellpoints, it is assumed that all “garden boreholes” registered during the City of Cape Town GAP registration process have remained operative since and are currently still in use.

2.8 Chronological review of past research work

Groundwater use in South African residential areas and the effect that this practice has on potable water demand has been investigated in the past. However, an acute lack of knowledge on this topic still remains and literature often only refers to it with a philosophical approach rather than in technical terms or by quoting quantitative figures or results.

This desk-top review addresses all previous studies and published work on this subject that could be found during the course of this research. These are listed in chronological order and discussed in brief hereafter.

2.8.1 Garlipp (1978) – Pretoria, Kroonstad and Rustenburg

The first work addressing the matter of groundwater use in residential areas that could be traced during this study was conducted by the University of Pretoria (UP) in the period from 1970 to 1977 (Jacobs *et al.*, 2011). The work was later included as a component of a masters' thesis published by the same university (Garlipp, 1978).

The main region covered in this early work was the Pretoria area where a large-scale survey comprising 10 627 stands was undertaken, of which 1 237 reflected borehole ownership, i.e. 11.6%. According to this study, the water saving effected on stands with boreholes as compared to stands without boreholes was 28.1% or an average saving of 422 l/stand/day. Unfortunately, the only two publications in peer reviewed journals relating to water use in Pretoria during the same period (Ellis and Van Duuren, 1974; Gebhardt, 1975) did not address the impact of groundwater use.

The towns of Kroonstad and Rustenburg were also covered during this study, but both involved significantly fewer stands. In Kroonstad a group of 59 stands with boreholes which were dispersed over the entire town were investigated. Around each stand with a borehole, a cluster of stands without boreholes was taken as a control group. The water consumption on stands with boreholes was found to be 3% less than that at stands without boreholes in the surrounding area.

In Rustenburg a single township of 341 stands, of which 85 with boreholes, was investigated. The average annual water consumption at residential stands with boreholes equated to only 54.7% of the average consumption on stands without boreholes, representing an average saving of 775 l/stand/day or 45.3%.

Figure 2.12 below illustrates that the difference in water consumption for stands in Rustenburg with and without boreholes can clearly be attributed to the possession and use of private GAPs. The average AADD for each group of stands was plotted against stand size and presented as a time series for the period between 1970 and 1977.

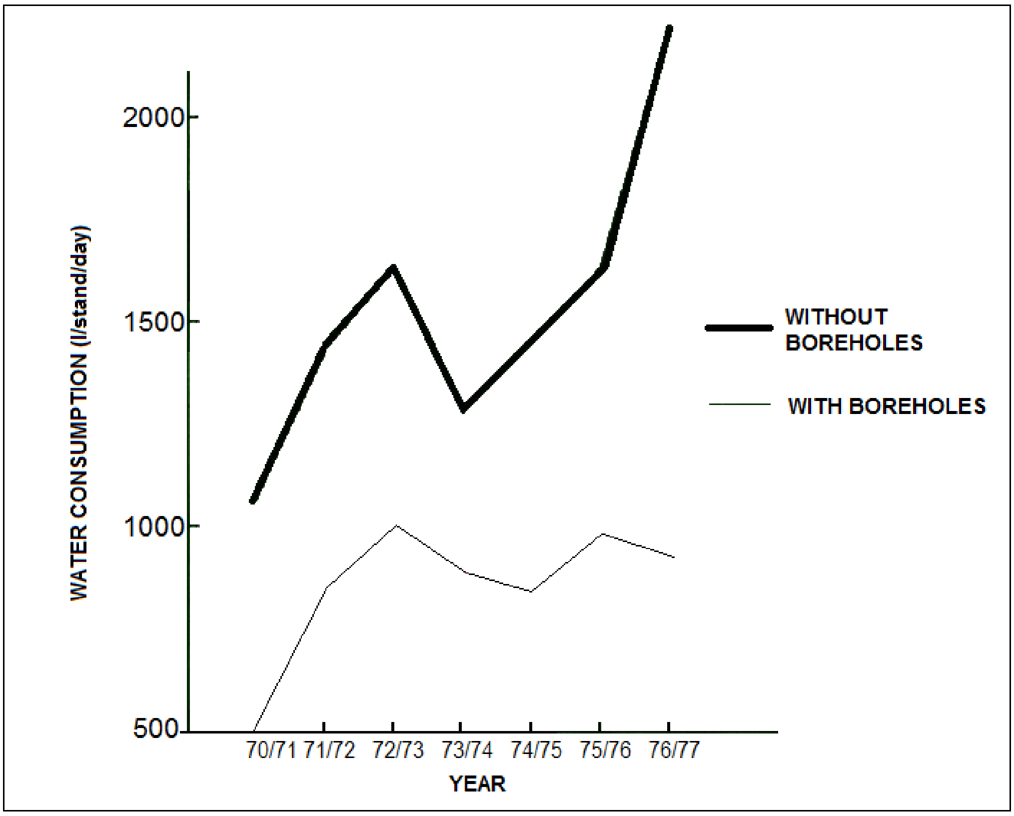

Figure 2.12: Water consumption patterns in Rustenburg for stands with boreholes versus stands without boreholes

Source: Garlipp (1978)

Even though the work by Garlipp (1978) dates back more than 35 years and the methods applied are dissimilar to that used with this research, it nevertheless has a much relevant focus and provides good measurable outcomes that will be used to compare with the results of this study.

2.8.2 Simpson (1990) and Elphinstone and Van der Linde (1990) - Pretoria

About a decade later a report was published by Simpson (1990) which contained the results of a study conducted in the municipal area of Pretoria over a period of nearly 3 years. The results contained in this report emanated from a research project funded by the Water Research Commission (WRC) and undertaken by the Council of Scientific and Industrial Research (CSIR).

More than 3 000 residential properties were evaluated for location, abstraction rates, groundwater levels and municipal water use. The main aim of the project was to assess the annual quantity of water abstracted from private boreholes in relation to the total quantity of water supplied by the municipal water supply system. This process and the methods used are described in a report by Elphinstone and Van der Linde (1990) which is an addendum to the main report by Simpson (1990).

The geographical region of the study area (formerly known as Transvaal) is the interior summer rainfall part of the South Africa. Residential properties with private boreholes in Pretoria were evaluated for location, groundwater levels, abstraction rates and municipal water use patterns (through the installation of water meters). Field work and data collection for this project spanned a period of two years and was concluded in January 1990.

The total number of properties with private boreholes in Pretoria at the time of the study was estimated by applying a stratified cluster sampling technique. The Pretoria municipal area was divided into 9 strata and a number of clusters of about 100 properties each were sampled within each stratum. Field workers were sent into each stratum and recorded which properties had boreholes and which did not. In total, 8 020 stands across some 72 clusters were surveyed, of which 2 941 properties, i.e. 36.7%, were identified as having an on-site private borehole.

The average weighted proportion of properties with boreholes across all 9 strata was calculated at 37.5%, with a maximum incidence of up to 60% in some areas. This proportion was applied directly to the total number of residential erven in the entire Pretoria municipal area, i.e. 80 536 stands in total. Subsequently it was estimated that roughly 30 000 properties in the study area had private boreholes (Elphinstone and Van der Linde, 1990).

As part of this project, 98 residential stands with boreholes and 439 without boreholes were monitored over a period of 24 months. The level of potable water (from municipal supply) used at these stands was investigated, while the volume of groundwater abstracted at those stands with boreholes was also determined. The municipal water usage of properties with private boreholes (where groundwater is abstracted) versus that of properties without boreholes was plotted graphically.

From these results, definite conclusions were made as to the impact of residential groundwater usage and the subsequent reduction in municipal water use at stands where these alternative sources were used. The study indicated that the average municipal water consumption at erven with boreholes was 0.82 kl/d compared with that of stands without boreholes, which was 1.04 kl/d. This is an average reduction in municipal water use of 0.22kl/d or 21% for properties with a private borehole. However, it was noted that the reduction in municipal water use was effectively “replaced” by an average groundwater abstraction of 1.78 kl/d at such stands (Elphinstone and Van der Linde, 1990).

Although this work could be considered somewhat out-dated, it remains similar, and particularly applicable, to this study as it reports significant detail, gives quantitative figures and lists specific conclusions.

2.8.3 Maclear (1995) - Cape Town

The study by Maclear (1995) which was published by DWAF noted the potential of the CFAU to supply groundwater for domestic use in the CMA. It was argued that residential wellpoints abstracting water from sand aquifers could significantly reduce the volume of potable water being used for garden irrigation.

As part of the study the author investigated the water consumption of an unknown number of residential stands in the Cape Peninsula between 1991 and 1995 before and after wellpoint installation at these stands. It was found that average reductions of between 60% and 80% in their summertime (September to April) water consumption were realised at middle-income households upon installation of wellpoints utilised exclusively for garden irrigation purposes – see Figure 2.13 below. The number of stands that formed part of this investigation is, however, unknown.

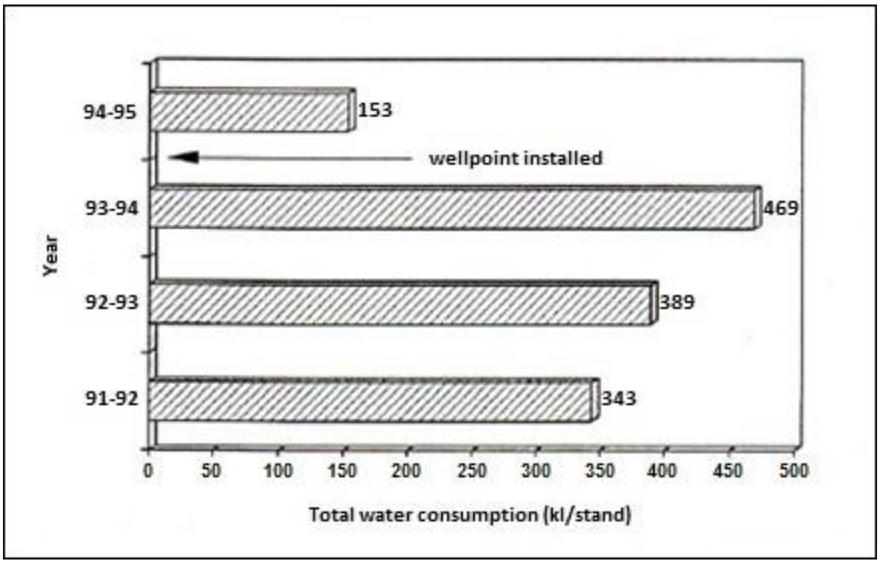

Figure 2.13: Reduction in summertime (September to April) water consumption at domestic stands upon installation of a wellpoint

Source: Maclear (1995)

While the work by Maclear (1995) focuses on Cape Town which is very similar to the study area of this research, it is regarded less ideal for comparison with the results of this study due to the fact that it reports on summertime water consumption only and because the number of stands that formed part of this study is not known.

2.8.4 Lomberg *et al*. (1996) - Port Elizabeth

Lomberg *et al*. (1996) published a report on a study conducted between 1993 and 1995 in Port Elizabeth which was funded by the WRC. One of the primary objectives of the study was to investigate the extent and effects of private groundwater abstraction in the Port Elizabeth municipal area by determining the number and distribution of boreholes in this area. This did not necessarily mean private residential boreholes only, but also included higher consumption municipal and non-residential boreholes as well.

The majority of boreholes in Port Elizabeth are privately owned (Lomberg *et al*., 1996) and public co-operation was therefore vital. Various methods were used to identify stands with boreholes, but the success rates were disparate. Press releases were issued and newspaper articles published, but these failed to enjoy the intended exposure.

Next, the municipality mailed census forms with the monthly accounts sent to all ratepayers, but the response was also poor. Of the more than 30 000 such forms sent out only 74 were completed and returned. The authors ascribed the lack of public co-operation mainly to a perceived threat of intervention and ultimate control of the use of groundwater by the Port Elizabeth municipality.

Subsequently the study team contacted the two main local contractors involved with borehole installations in the Port Elizabeth area and obtained their logbooks. In this way, a further 161 stands with boreholes could be identified within the study area, which brought the total to 238 stands, of which 216 stands were located on private residential property. Of these, 37 private boreholes were equipped with water meters as part of a monitoring program to record the volume of groundwater used at these stands. The data collected from this process was ultimately used to estimate the total volume of groundwater abstracted annually in the Port Elizabeth municipal area.

Furthermore, the study reported on various hydrogeological aspects applicable to the study area such as groundwater quality, aquifer potential and seawater intrusion. However, no figures with regard to the average daily groundwater use or estimated reduction in municipal water consumption at those residential erven with boreholes were quoted, which makes this study less relevant to the current research.

2.8.5 Saayman and Adams (2001) – comparative study between Cape Town and Perth

A detailed comparative study by Saayman and Adams (2001) involving the cities of Cape Town and Perth, Australia investigated the groundwater use in urban areas of these two metropolises. The study was aimed at evaluating the feasibility of using privately owned GAPs in the CMA for garden irrigation and the unique learning opportunity that Perth could offer in this regard.

Cape Town is set at the southern tip of Africa and surrounded by ocean and prominent mountain ranges that provide a natural barrier to rain-bearing frontal systems approaching the continent from the south Atlantic. Perth is located on the south-western “corner” of Australia, more than 10 000 km east of Cape Town. It is by far the largest urban centre in Western Australia, with a Mediterranean type climate characterized by wet winters and dry summers.

However, Cape Town and Perth share various attributes not only in terms of geographical setting (e.g. coastal location and similar latitude) and climate, but also the fact that both cities are underlain by major unconfined, shallow aquifers. Large parts of the CMA are situated on the CFAU, while Perth is located on the highly permeable Swan Coastal Plain, consisting of quaternary sand and limestone.

Perth is a fast growing city that experiences a continued increase in water demand and presently relies on surface reservoirs and groundwater for domestic supply. Saayman and Adams (2001) reported that around 50% of the city’s annual domestic consumption is derived from groundwater sources. As a consequence of its focus on using groundwater, the city has seen a proliferation of domestic boreholes which have been used primarily as an alternative to potable water for garden irrigation. It is estimated that 1 in every 4 houses in Perth has a private borehole that is used for garden watering (Appleyard *et al*., 1999). This strategy has resulted in significant savings in the city’s treated water usage.

The study included a visit by the authors to both cities during their research. The report compares the annual precipitation, hydrogeology, status of water supply, groundwater quality and current groundwater management of the two cities. One outcome of the study was that groundwater use in residential areas is far more prevalent in Perth than in Cape Town.

The report concluded with remarks as to what has to be done politically and socially in order to strategically place Cape Town in a position where the use of groundwater will become a more popular and sustainable source of water supply, especially for domestic use, which will strengthen the city in the development of an integrated approach to water resource management.

This work did not contain any detailed information with regard to domestic water use, surveys as to where private GAPs are located in either of the cities or the impact that private groundwater use has on potable water consumption at residential stands with GAPs. From this perspective the reported findings are considered valuable from a strategic point of view, but limited technically and in relevance to this research.

3. Hermanus – a pilot study

3.1 Introduction

The town of Hermanus was chosen on which to base a pilot study for the purposes of this research purely owing to the timely availability of suitable data and the fact that it could fittingly be performed before the main part of the study (which is based on Cape Town) was conducted.

The method by which the data was verified and processed, as well as the comparative analysis with existing water demand guidelines that formed part of this pilot study, set the way for the full-scale application thereof on the Cape Town data.

3.1.1 Purpose of pilot study

The main purpose of the pilot study was to test the proposed methodology to be used for the verification and analysis of Cape Town data on a much larger scale and to assess the outcome of this when applied to the identified group of stands with private GAPs in Hermanus.

The secondary aim and objective of the pilot study was as follows:

- identify, capture and verify residential stands in Hermanus where on-site groundwater are utilised through the possession of private GAPs; and
- compare the average AADD of those stands in Hermanus with private GAPs to the average water demand of residential stands as per various published AADD guidelines within specific erf size categories.

The above allowed the impact of residential groundwater use on municipal water demand in serviced areas of Hermanus to be investigated on a limited scale with this pilot study.

3.1.2 Study area

The study area for the pilot study is the town of Hermanus, approximately 120 km east of Cape Town and situated within the Overstrand municipal area along the south coast of the Western Cape. The Greater Hermanus Area (GHA) is a very popular destination for many holidaymakers and tourists.

This study is limited to the Eastcliff and Northcliff suburbs of Hermanus as these were the only areas for which data was readily available. The eastern suburbs of Hermanus namely Voëlklip, Kwaaiwater and Fernkloof and the nearby areas of Sandbaai, Onrus, Vermont and Hawston located to the west of the GHA were therefore not included. A map of the GHA is shown in Figure 3.1 below.

Figure 3.1: Map of the Greater Hermanus Area

The name "Hermanus" will be used hereafter to refer to the study area meaning the suburbs of Eastcliff and Northcliff only.

3.2 Hermanus hydro-census

In May 2000 a mini hydro-census was completed in Hermanus for the local Overstrand Municipality (Tennick, 2000), initiated by a retired geohydrologist, Mr Frank Tennick, formerly from Zimbabwe and who now lives in Onrus. Mr Tennick approached the local municipality in 1999 to propose that a groundwater data base be set up to evaluate the quantity and quality of groundwater abstracted in the Hermanus area.

Eventually Mr Tennick was appointed by the municipality to undertake a hydro-census in the Eastcliff and Northcliff suburbs of Hermanus so as to identify stands in the area where groundwater is used in a private capacity. The survey was paired with an on-site geohydrological investigation of the stands identified through this process.

The primary objectives of the study by Tennick (2000) were as follows:

- identify the number and record the spatial distribution of GAPs in the study area (i.e. Hermanus);
- measure the fluctuation of groundwater levels (rest water levels) over a period for a dedicated group of GAPs (from those identified during the study);
- monitor the quality of groundwater abstracted at the dedicated group of GAPs over a period; and
- estimate the volume of water abstracted annually at the GAPs identified during the study (without metering).

Initially an attempt was made to conduct a door-to-door survey whereby residents were requested to supply information about the GAPs on their properties by completing a questionnaire. However, it was soon realised that many residents were reluctant to provide information in this regard.

The exercise was later abandoned when it was established that the majority of boreholes and wellpoints in Hermanus were installed by a local entrepreneur, Mr John Marriott, between 1969 and 1990. He kept a record of all installations in a log book which included the name of the owner or occupant at the time, the date, address, erf number, depth and geology for each GAP installed.

Mr Marriott made the information available to Mr Tennick when the value of it was explained to him. His records, although incomplete, gave a good indication of where GAPs were located in the area and were ultimately the only data which contributed towards the hydro-census.

The study by Tennick (2000) concluded with the following findings:

- At least 278 wellpoints, 13 boreholes and 7 dug wells (a total of nearly 300 GAPs) are located at residential stands in Eastcliff and Northcliff;
- Groundwater abstracted from private GAPs at these stands is used mainly for domestic gardening purposes;

- Average depth of water table in the study area is approximately 2.30 m below the surface;
- Groundwater in the study area generally has a brownish colour, owing to the high iron and manganese content; and
- Average abstraction rate for boreholes and wellpoints in the study area was estimated at about 1 000 l/h.

However, Tennick (2000) did not report on the effect that private groundwater use at these stands has on their municipal water consumption. This pilot study therefore partly serves this purpose as the verified hydro-census data is used in a comparative analysis, whereby the municipal water consumption at these stands is compared with recently published water demand guidelines.

3.3 Data processing

The original log book data and the subsequent report submitted to the Overstrand Municipality were obtained from Mr Tennick in electronic format and used as a base for this pilot study. No additional data was sourced for these purposes.

To ensure the integrity of the final data base, various data-cleaning phases were implemented by which the original data was captured and verified. This method of data processing is discussed in more detail hereafter.

3.3.1 Verification of original data

The original data (total number of 378 entries) were scrutinised and categorised as the first step of the verification process. This included arrangement of the data set into columns, keeping only information imperative to this study such as the name of the owner/occupant of the property at the time, the date the GAP was installed, street address, erf number (if supplied) and suburb or town.

This enabled the elimination of entries for stands with GAPs in areas outside the immediate study area (22 such records were found). Entries with no or insufficient information e.g. no street address, with only the suburb or name of owner/occupant supplied (73 such records were found) were also eliminated.

Furthermore, all entries of which the name or description clearly represented non-domestic stands i.e. commercial or industrial stands, schools, churches, sport fields, farms, developments and government or municipal institutions (23 such records were found) were also removed from the data set.

Entries with incomplete street addresses, i.e. street names and names of owners or occupants at the time only, but without street or erf numbers (91 such records were found) were not removed but marked for verification through other methods at a later stage. The remaining data, being those entries with complete addresses (169 records in total), was considered to be sufficient for further processing and therefore kept.

The remaining entries were categorised alphabetically, after which all clear duplicate entries were marked and grouped together. Duplicate entries may possibly represent stands where additional GAPs were installed or maintenance was required after the initial installation. Nevertheless, all duplicate entries were removed from the verified data set.

The known information for those entries with incomplete street addresses was then used to verify the full addresses in an old telephone directory (Telkom, 1988), dated towards the end of the period for which the data was available. This verification process was only possible for cases where the owner or occupant of the property at the time of installation was still listed in the telephone directory being used for this purpose.

The success rate of entries positively verified in this manner was 47% (43 out of 91 records with incomplete addresses). These were then added to the set of entries with complete addresses verified previously to form a set of “usable” data consisting of 212 entries in total.

A summary of the original data upon categorisation and verification is given in Table 3.1.

Table 3.1: Summary of original data upon categorisation and verification

Category description		Number of stands	
		Upon categorisation	**Upon verification**
Residential stands (as per the initial classification)	Complete street address	169	169
	Incomplete street address *	91	43
	No or insufficient data	73	Not applicable
	Stands outside study area	22	
Non-domestic stands		23	
Total		**378**	**212**

* Entries with incomplete street addresses verified with Telkom (1988)

3.3.2 Capturing unique stand attributes

The next step was to capture unique attributes such as erf size and water demand of stands within the data set of "usable" entries. This was done by using a GIS-based management tool, namely Infrastructure Management Query Station (IMQS) which is commercial software that renders asset and consumer information across various municipalities in South Africa. The IMQS software is underpinned by a versatile data integration layer that makes it possible to take on multiple sources of information from different systems and data bases. The application extracts, integrates and transforms data from multiple asset classes into information appropriate for making informed asset management decisions (IMQS, 2012).

One such data base from which IMQS sources specific consumer and property related information is a commercial software package named Swift that was developed to perform statistical analysis of data held in municipal billing systems and that has been used by municipalities throughout South Africa for more than a decade Fair (2012).

The Swift program interrogates various treasury data bases and enables the user to analyse recorded water consumption data from individual consumer connections (Jacobs *et al*., 2004). Jacobs and Fair (2012) define Swift as a technical tool that focuses on analysing water demand and provides sufficient information to analyse water usage based on meter readings with certain filters and technical criteria. Fields in the Swift data base contain information on stand-related data, such as the owner, consumer, address, land use, zoning, water consumption and tax tariffs of each stand in an area for which the municipal treasury data base contributes towards the Swift data base.

IMQS could therefore fittingly be used to visually inspect certain aspects of the treasury records of Overstrand Municipality for each stand in the "usable" data set of 212 entries. The stands being scrutinised were verified further with this process based on address, erf number, land use, zoning and water consumption patterns, whilst obtaining the AADD and stand size for each of these entries. All duplicate entries that surfaced during this process (56 such entries were found), stands listed on IMQS as being zoned for non-domestic use (11 such entries were found) and entries of which the addresses could not be found on the IMQS data base (9 such records were found) were marked and removed from further assessment.

The AADD values obtained from IMQS are based on water consumption data from Swift that uses actual metered readings over a period of 12 months to calculate the water demand of these stands. Stands for which water consumption records were not available on IMQS, or were considered to be incomplete due to water meter readings for some calendar months being zero (22 such records were found), were also discarded as they give incorrect AADD values that do not represent the true water demand of these stands. Possible reasons for such flawed records could be faulty water meters, erroneous meter readings or dwellings used sporadically as holiday homes.

The "usable" data set, less all the entries that were removed, ultimately gave a final set of 114 residential stands (i.e. 30% of the original 378 entries) as shown in Table 3.2.

Table 3.2: Summary of stands scrutinised with IMQS

Category description		Number of stands
Final set of residential stands		114
Unusable data	Duplicate entries	56
	Non-domestic stands	11
	Unknown stands (not found on IMQS)	9
	No or incomplete water consumption data	22
Total		**212**

Next the AADD values and stand sizes for all the stands in the final data set were obtained by manually looking up each stand in IMQS. These are the only attributes required for a comparative analysis whereby the water demand of those stands with GAPs identified in the study area were to be plotted against stand size and compared with empirical AADD guidelines.

This pilot study was initially done in February 2009 at the start of this research. The AADD values extracted from IMQS for this investigation was based on a Swift analysis of water consumption for the Overstrand municipal area over a 12 month period between July 2006 and June 2007. At the time of the initial pilot study, this was the latest processed data readily available for these purposes.

Finally, it must be mentioned that sensitive information such as the names of consumers and owners, personal details, account numbers and property valuations was treated confidentially and was not extracted from IMQS during this process or required for the purposes of this study.

3.4 Comparative analysis

The AADD values (l/d) and stand sizes (m^2) extracted from IMQS were tabled in Microsoft Excel (.xls) format to facilitate further processing. The water consumption data could now be plotted against recently published water demand guidelines based on stand size for simple comparison.

A scatter plot of the AADD values versus stand size for all 114 entries in the final data set is shown in Figure 3.2 below.

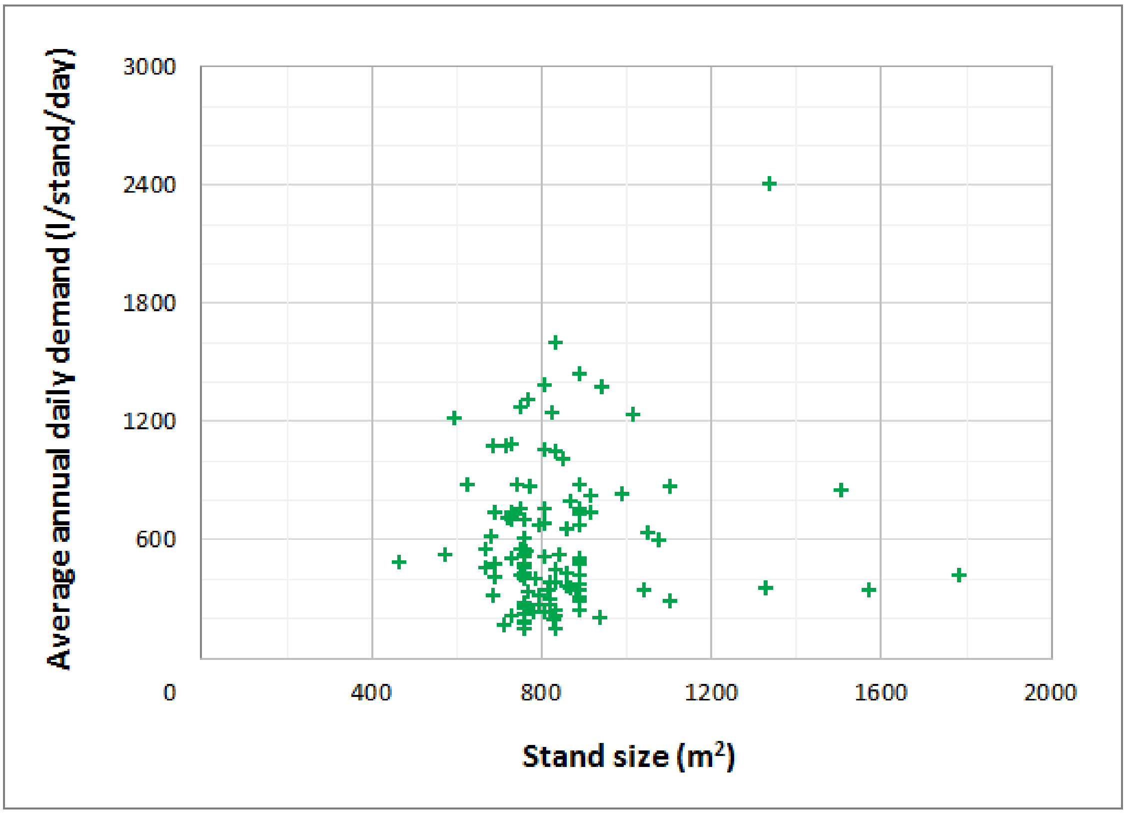

Figure 3.2: Average daily water demand of residential stands with GAPs in Hermanus versus stand size

The data points in Figure 3.2 are mainly grouped together, with 98 of the 114 records (i.e. 86%) located in the range of stand sizes between 650 m^2 and 950 m^2. This stand size range could fittingly be divided into three interval classes, each with a bound of 100 m^2 ranging from 700 m^2 (650 - 750 m^2) to 900 m^2 (850 - 950 m^2). The spread of these 98 samples across the three stand size classes are shown in Table 3.3 below.

Table 3.3: Spread of stands with GAPs in Hermanus per stand size class

Stand size class (m^2)	**Number of stands in class**
700	18
800	56
900	24
Total	**98**

The 98 samples in these three stand size classes will form the basis of the comparative analysis between the water consumption data and three separate AADD guidelines that is presented graphically and briefly discussed hereafter.

3.4.1 Red Book (CSIR, 2003)

The "Red Book" AADD guideline (CSIR, 2003) is the most commonly used South African design guideline for the estimation of domestic water demand. The guideline consists of an upper and lower limit that represents an envelope of residential water demand as a function of stand area for erf sizes between 300 m^2 and 2 000 m^2.

The actual water consumption data of all 114 stands in the final data set was first scatter plotted against the upper and lower limits of the "Red Book" guideline as shown in Figure 3.3 below.

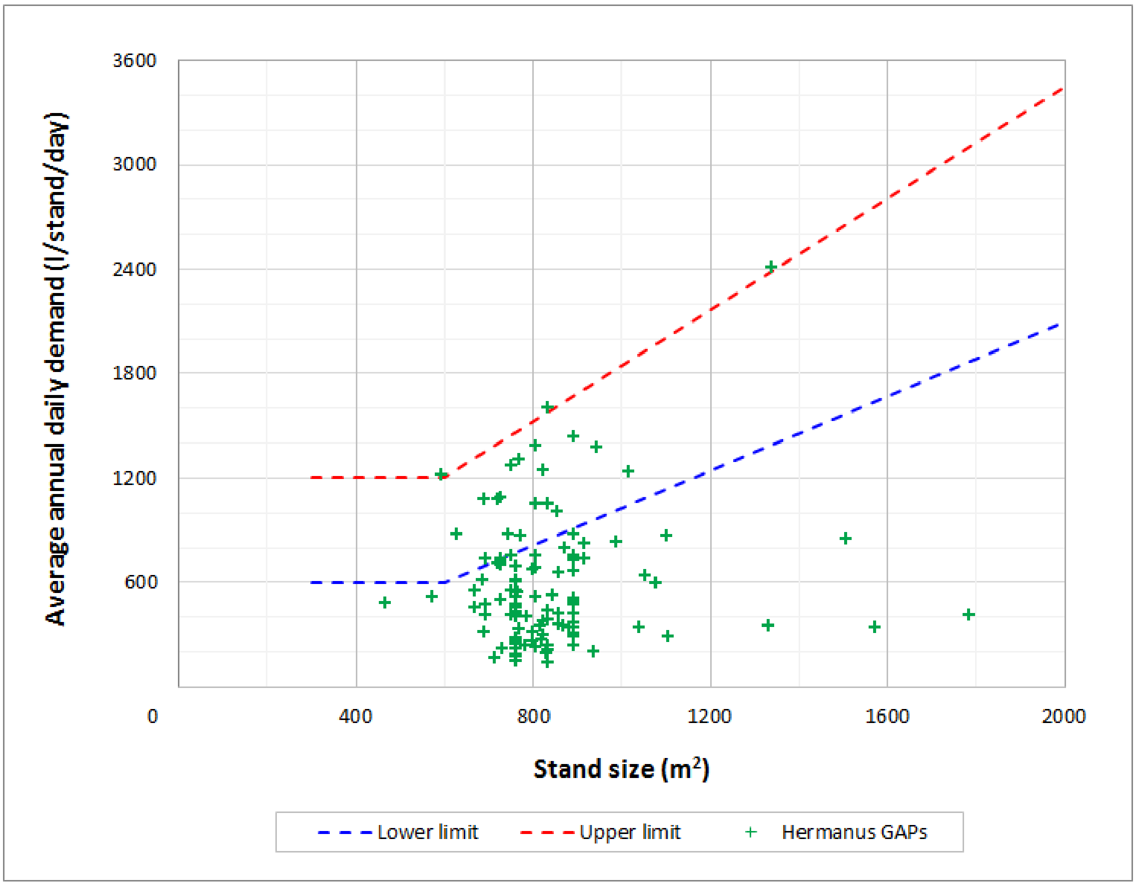

Figure 3.3: Average daily water demand of stands with GAPs in Hermanus versus "Red Book" guideline

It is clear from Figure 3.3 that a majority of the data points are clustered below the lower limit of the "Red Book" guideline. In fact, only 20 of the 114 points (i.e. 17.5%) are placed above the lower limit of the guideline.

Although previous studies have labelled the "Red Book" model as too conservative, the fact that more than 80% of the data points fall below the recommended water demand envelope serves as some indication as to the possible reduction in potable water usage at these stands with on-site GAPs.

In an attempt to better illustrate this, the actual AADD values for the 98 samples in the range of stand sizes between 650 m^2 and 950 m^2 were columned against the upper and lower limits of the "Red Book" guideline for the three stand size classes defined previously - see Figure 3.4 below.

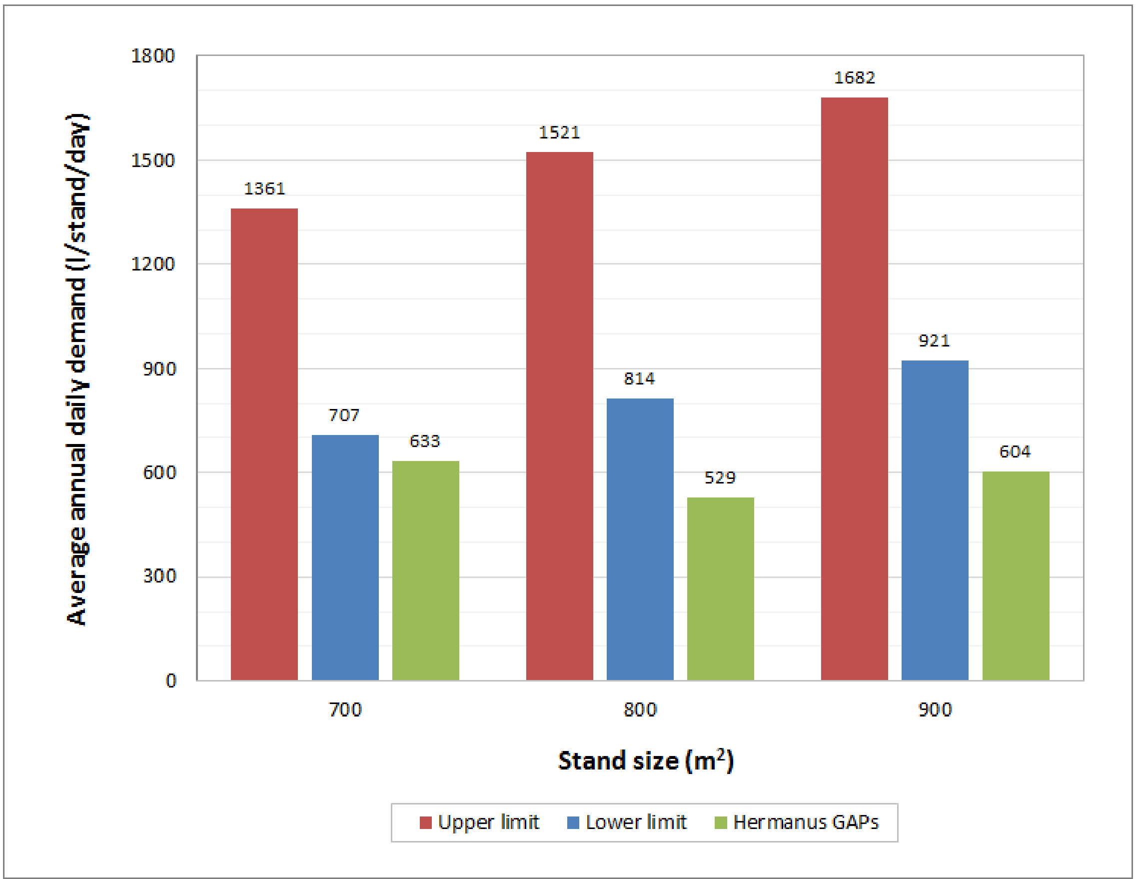

Figure 3.4: Comparative histogram for the average daily water demand of stands with GAPs in Hermanus versus "Red Book" guideline

The comparative histogram in Figure 3.4 provides a visual impression of reduced water consumption at stands with GAPs identified in the study area. It is clear from this illustration that the average daily water demand of stands in each of the interval classes falls below the water demand proposed by the "Red Book" guideline.

3.4.2 Jacobs *et al*. (2004)

Jacobs *et al*. (2004) proposed unique models for the estimation of the annual average residential water demand with stand size as single explanatory variable. Separate models were presented for different rainfall and geographic (inland and coastal) regions in South Africa, with corresponding envelope curves.

The town of Hermanus is situated along the south coast of the Western Cape in a winter rainfall region. For this reason the guideline curve for "coastal winter rainfall regions" from Jacobs *et al*. (2004) was used for this comparison. The guideline is represented by two linear equations with separate slopes for stand sizes ranging between 50 m^2 and 2 050 m^2. The mathematical form of the guideline curve is:

$$Q = \begin{bmatrix} (0.00110595)\,A + 0.287 & (50m^2 \leq A < 840m^2) \\ (0.00056253)\,A + 0.745 & (840m^2 \leq A < 2\,050m^2) \end{bmatrix}$$

where Q = average annual water demand (kl/stand/day)

and A = single residential stand size (m^2)

The upper boundary of the envelope also consists of two sections with the same two slopes as that of the guideline curve but with a different point of intersection. The mathematical description of the upper envelope curve is:

$$Q_{HIGH} = \begin{bmatrix} (0.00110595)\,A + 0.551 & (50m^2 \leq A < 1\,100m^2) \\ (0.00056253)\,A + 1.148 & (1\,100m^2 \leq A < 2\,050m^2) \end{bmatrix}$$

where Q_{HIGH} = upper boundary of the envelope of average annual water demand (kl/stand/day)

and A = single residential stand size (m^2)

The lower boundary of the envelope is represented by a single linear curve. The mathematical description of the lower envelope curve is:

$$Q_{LOW} = [(0.0007000)\ A + 0.200 \qquad (50m^2 \leq A < 2\ 050m^2)]$$

where Q_{LOW} = lower boundary of the envelope of average annual water demand (kl/stand/day)

and A = single residential stand size (m^2)

The actual data of the final set of 114 stands were plotted against the guideline and envelope curves presented by Jacobs *et al*. (2004) as shown in Figure 3.5 below.

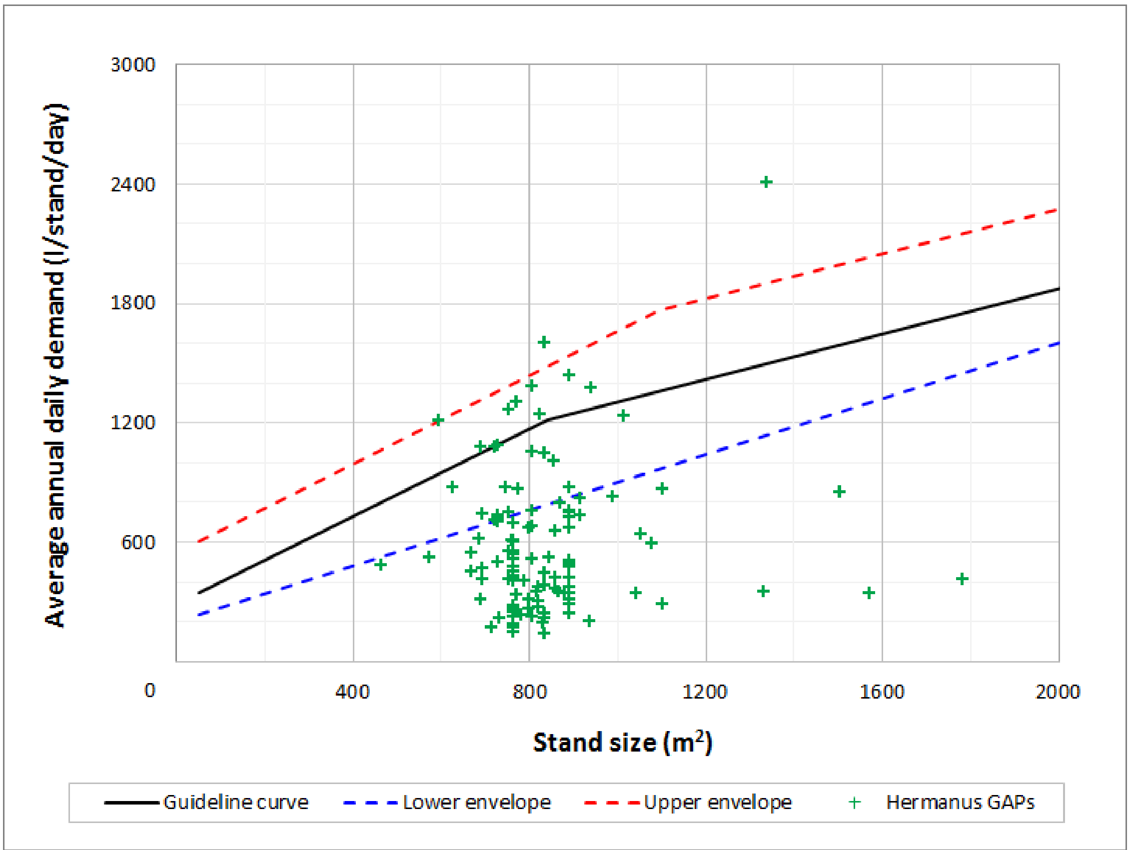

Figure 3.5: Average daily water demand of stands with GAPs in Hermanus versus guideline by Jacobs *et al*. (2004)

The largest share of the data points are grouped below the lower boundary of the envelope as can be seen in Figure 3.5. Only 25 of the 114 points (i.e. 22%) are placed above the lower envelope boundary, of which just 10 points are situated beyond the actual guideline curve.

Similar to the actual water consumption data plotted against the "Red Book" guideline (see Figure 3.3), almost 80% of the data points in Figure 3.5 fall beneath the recommended envelope of the guideline by Jacobs *et al*. (2004). This is another suggestion of reduced potable water demand at these stands.

The values of the estimated AADD (Q), upper envelope boundary AADD (Q_{HIGH}) and lower envelope boundary AADD (Q_{LOW}) were calculated for the three interval classes defined in the 650 m^2 to 950 m^2 stand size range by using the aforementioned equations. The actual AADD values of all 98 stands spread across these stand size categories were stacked against the calculated values of the guideline curve and envelope boundaries as shown in Figure 3.6 below.

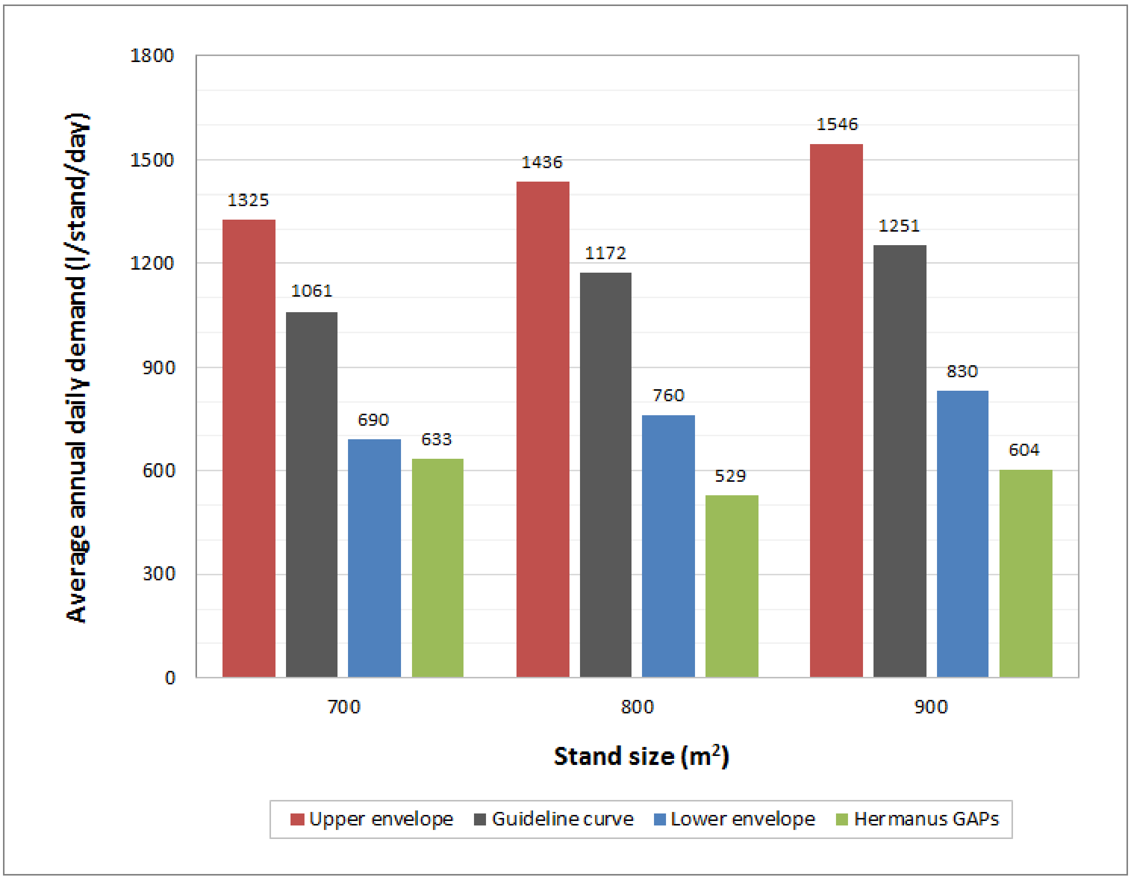

Figure 3.6: Comparative histogram for the average daily water demand of stands with GAPs in Hermanus versus guideline by Jacobs *et al*. (2004)

The histogram in Figure 3.6 shows the average daily water demand of the residential stands with GAPs forming part of this analysis to be less than what is suggested by the guideline of Jacobs *et al*. (2004) for each of the three stand size classes.

3.4.3 Van Zyl *et al*. (2008)

Van Zyl *et al*. (2008) analysed metered records spanning a period of at least 12 months from various municipal treasury data bases nationally. Consequently a new guideline curve with confidence limits specific to South Africa was proposed, to assist with the estimation of domestic water demand.

This was achieved by carrying out a single regression analysis of all the records of single residential stands to determine the mathematical equation representing the average AADD of residential stands as a function of average stand size for areas ranging from 100 m^2 to 4 000 m^2. Dissimilar stand size classes with ranges of between 250 m^2 and 1 000 m^2 were used for this analysis.

The equation for the non-linear guideline curve and envelope around it based on the 95% (+) and 5% (-) confidence limits are given below:

$$Ln(AADD) = -1.610 + 0.297\, Ln(Std\ Area)$$

$$\pm (1.6449)(0.43865)\sqrt{1 + \frac{(Ln(Std\ Area) - 6.4124)^2}{666\ 977}}$$

where *AADD* = average annual water demand (kl/stand/day)

and *StdArea* = stand area (m^2)

The first part of the equation describes the single variable regression curve and the second part, the 95% (+) and 5% (-) confidence limits. The confidence limits indicate the boundaries wherein (below which) a given percentage of AADD values would lie. The 5% confidence limit will be used as the lower envelope boundary for the purposes of this comparison.

The water consumption figures of all 114 stands in the final data set were plotted against the guideline curve and the 5% confidence limit of Van Zyl *et al*. (2008) as presented in Figure 3.7 below.

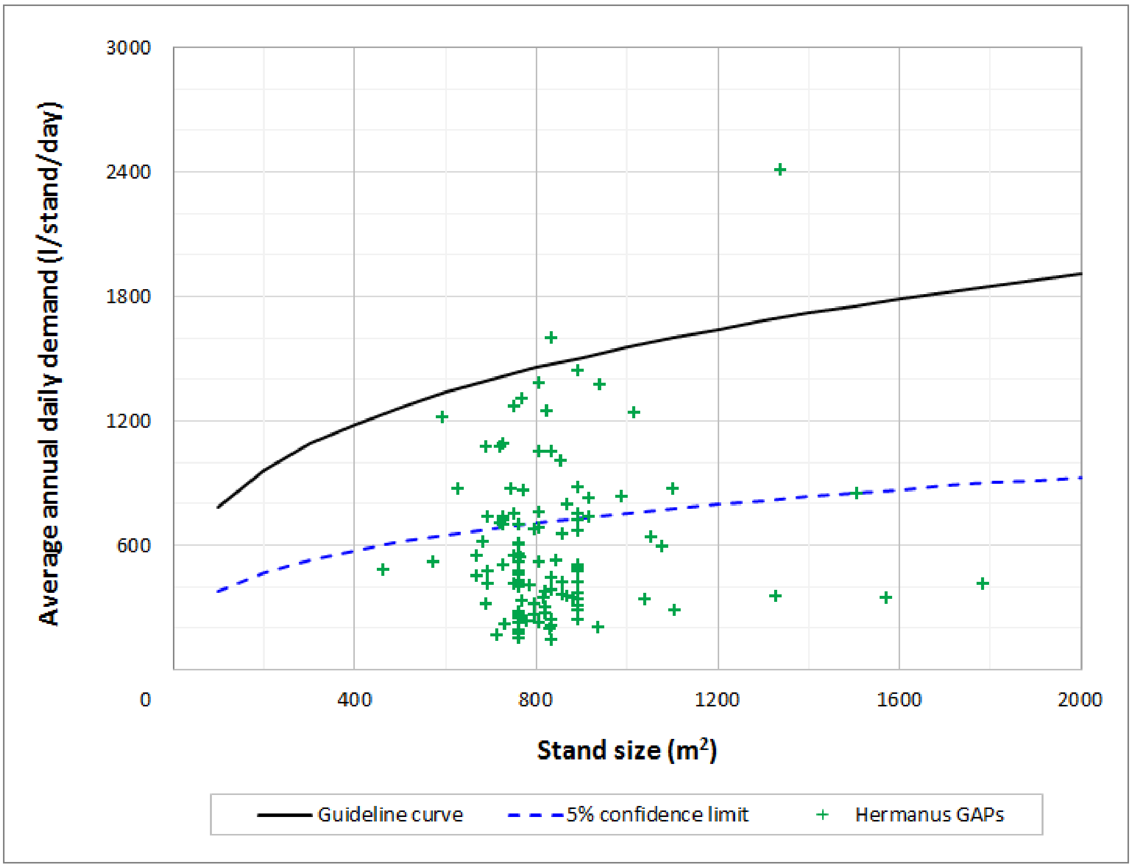

Figure 3.7: Average daily water demand of stands with GAPs in Hermanus versus guideline by Van Zyl *et al*. (2008)

A cluster of data points in Figure 3.7 falls below the 5% confidence limit of the guideline. In total 33 of the 114 points plotted (i.e. 29%) are placed above the 5% confidence limit, of which only 2 points are beyond the guideline curve. This means that more than 70% of the actual AADD values fall below the lower envelope boundary represented by the 5% confidence limit. It suggests some level of reduced water demand on average at these stands, since the 5% confidence limit indicates the theoretical boundary below which 5% of all AADD values of single residential stands would lie.

The AADD values, according to the guideline curve and the 5% confidence limit, were calculated for the three stand size classes of Table 3.3 and stacked against the actual average AADD value of each stand size category for all 98 stands within this range. This comparison is shown in Figure 3.8.

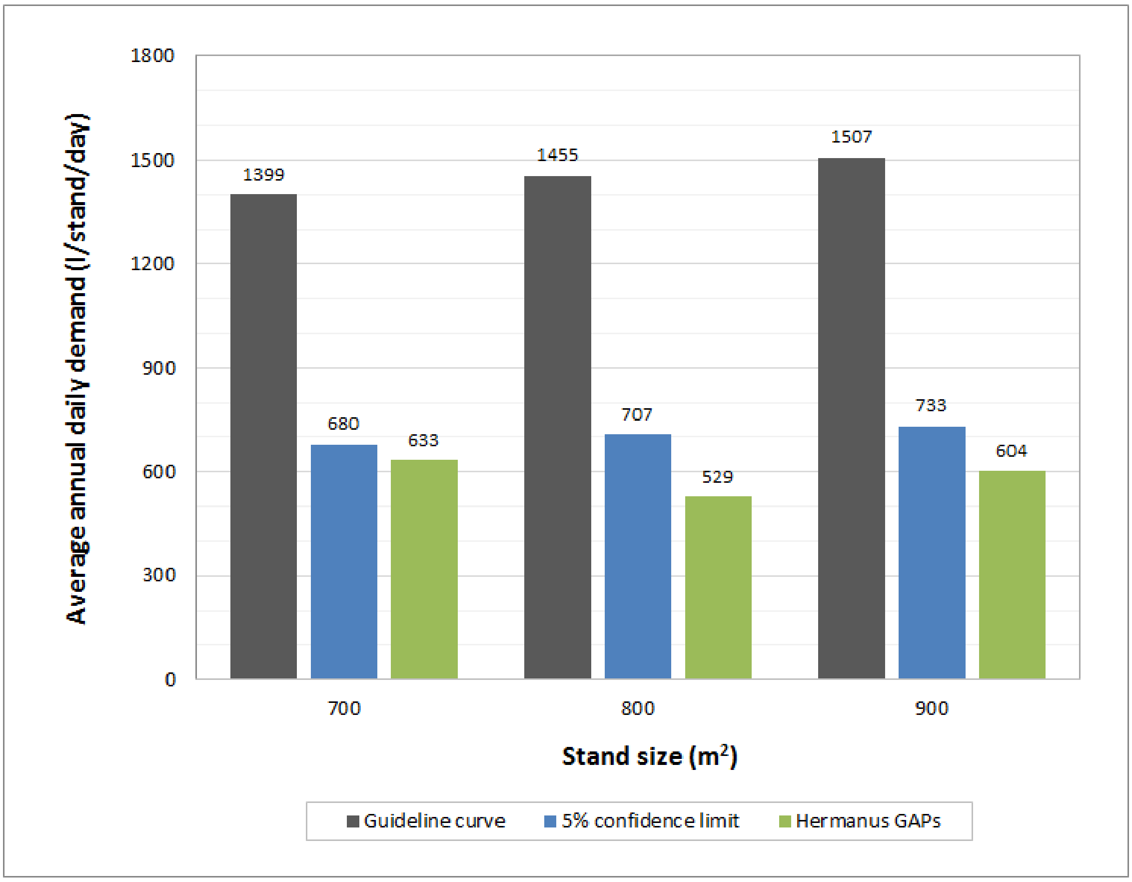

Figure 3.8: Comparative histogram for the average daily water demand of stands with GAPs in Hermanus versus guideline by Van Zyl *et al*. (2008)

The histogram in Figure 3.8 shows the reduced potable water demand at residential stands with GAPs in Hermanus forming part of this investigation compared to the guideline of Van Zyl *et al*. (2008). The average AADD values of the stands represented by the “Hermanus GAPs” columns in Figure 3.8 is lower than the calculated AADD values of the 5% confidence limit for all three stand size classes.

The 5% confidence limit of the guideline indicates a 5% probability that the mean AADD of the sampled stands will lie within (below) this confidence limit. The fact that the actual mean AADD values of all three interval classes are less than the AADD values of the 5% confidence limit for the corresponding stand sizes is therefore proof of a reduction in the mean AADD of this group of residential stands with GAPs.

3.5 Conclusion and comments

The records used for the pilot study were the only appropriate data that was readily available for the study area at the time of the initial investigation without having to conduct another dedicated hydro-census. The original data was obtained from a separate study independent of this research and went through a thorough verification process to give a final data set that was used for the comparative analysis. Data was not used or removed from the original set of records simply to fit a desired distribution or illustrate a certain trend. All entries with valid data were therefore included in the final set, regardless of the relative extent of each.

The sample size of the final data set (114 records in total) is considered to be acceptable to process, compare and draw conclusions from, considering the total number of residential erven in the study area (1 053 stands in total). In other words, the final set of data includes about 10% of all residential properties in this area.

Based on the comparative analysis performed with this pilot study, the main conclusion that can be drawn from it is that residential stands with GAPs in Hermanus show reduced water consumption when compared to recently published water demand guidelines. The average AADD of the group of residential stands investigated is notably lower than that suggested by the "Red Book" and guidelines presented by Jacobs *et al*. (2004) and Van Zyl *et al*. (2008). Histograms were used to portray the results of the comparative analysis and gave a good visual impression of the reduced water demand of stands in the final data set compared to these guidelines for all the stand size classes that were considered.

This pilot study aimed to test the proposed methodology, method of presentation and expected outcomes of the main research on a much smaller scale. The average reduction in AADD for the specific size range was not quantified though, as the sample size of the three size classes was considered too small for an accurate estimate to be made. However, the techniques applied during the verification process, data processing and comparative analysis can now serve as basis for the full-scale application with a similar investigation in the Cape Peninsula hereafter.

4. Data acquisition and analysis

4.1 Introduction

The records from the CCT's GAP registration process (from 2000 to 2006) were identified as the ideal source of information for this study – presuming that they could be obtained. Several individuals at the CCT were contacted in an attempt to trace the original registration data (hopefully in GIS format) but initially without any success. Eventually all the original registration records could be traced as the CCT had, fortunately, kept them all in a safe place at the Technical Operations Centre (TOC) in Bellville.

The CCT agreed to make the information available for the purposes of this research (Potgieter, 2008) and three files containing the original registration forms were collected from the place of storage in June 2008. However, the original registration data was available only in hard copy format and had never been processed or converted to electronic format. The identification process of properties in this study was therefore based only on the data obtained from the CCT registration process.

4.2 Data processing

Wright and Jacobs (2010) reported on the methodology employed at the start of this research by which the data obtained from the CCT registration process was verified, assessed and categorised before it could be used for further analyses. The original data was first captured electronically, after which a stringent verification process was applied in order to ensure the veracity of the final data base. This process is described exclusively hereafter.

4.2.1 Electronic data capturing

The first step towards the verification and processing of the raw data on the original registration forms was to capture it electronically. All the data was converted to .xls format during a 6 month period, listing the entries in numerical order according to the registration numbers. Relevant information supplied with each entry was captured on the spread sheet, regardless of whether the street or suburb names were unclear, address incomplete or the correctness thereof was in doubt. The name and date supplied with each registration were deemed irrelevant for the purposes of this study and were not captured. Eventually a complete set of the original data in electronic format was compiled.

Next each entry was categorised in terms of the land use (if it could be derived from the registered information) and the alternate water source it was registered for (e.g. groundwater, greywater, rainwater or other). This was done using disparate and easily distinguishable colours for each of the different categories and produced an interesting spread of categories comprising 4 487 entries in total, as seen in Table 4.1.

Table 4.1: Number of stands registered per category

<table>
<tr><th colspan="2">Category description (stand type)</th><th rowspan="2">Number of stands in category</th></tr>
<tr><td rowspan="5">Single residential stands</td><th>Source</th></tr>
<tr><td>Groundwater *</td><td>4 272</td></tr>
<tr><td>Greywater</td><td>72</td></tr>
<tr><td>Rainwater</td><td>11</td></tr>
<tr><td>Other</td><td>10</td></tr>
<tr><td colspan="2">Security complexes or private developments, retirement villages and blocks of flats</td><td>16</td></tr>
<tr><td colspan="2">Farms and small holdings</td><td>17</td></tr>
<tr><td colspan="2">Commercial and industrial stands</td><td>23</td></tr>
<tr><td colspan="2">Schools and tertiary institutions</td><td>29</td></tr>
<tr><td colspan="2">Churches and convents</td><td>18</td></tr>
<tr><td colspan="2">Sport fields and parks</td><td>16</td></tr>
<tr><td colspan="2">Hospitals and clinics</td><td>3</td></tr>
<tr><td colspan="2">Total</td><td>4 487</td></tr>
</table>

* Only entries for which groundwater was indicated as alternate water source were evaluated further in this study

Source: Wright and Jacobs (2010)

For the purposes of this study only single residential stands for which groundwater was indicated as alternate water source during the registration process (4 272 entries in total) will be used and were kept. The remaining entries, being those registered for use of greywater, rainwater or other water sources and all non-residential stands, were eliminated from further verification and consideration.

4.2.2 Verification of original data

Verification of all 4 272 entries in the category for single residential stands with GAPs was done manually. The verification process did not include any physical surveys or hydro-census to confirm the details of the stands identified for the purposes of this research. This would have been completely impractical considering the time constraint and lack of resources available for this research.

The entire data set containing residential stands with GAPs was scrutinised manually in terms of street addresses and suburbs on a one-by-one basis. The street address of each entry was verified for the spelling of the street name and the accuracy of the street extension indicated on the registration form. Based on the relatively large number of errors found, it would have made sense to capture the data in electronic format from the outset, perhaps by way of a web-based input form with "drop-down" lists, and include some type of verification of the properties when captured if possible. This process was the first step towards identifying the properties spatially on a GIS-based system.

Every street name was verified by employing various sources such as metropolitan street guides (Map Studio, 2005), the Yellow Pages website (Yellow Pages, 2008) and Google Maps (Google, 2009). This also made it possible to correct the spelling of some obviously misspelled street names and to decipher almost illegible handwriting in other cases. For many entries the street extensions indicated were found to be false, mainly due to incorrect translation (on behalf of the registrar) from Afrikaans to English. A couple of examples hereof are shown in Table 4.2 below:

Table 4.2: Examples of incorrect translation of street extensions

Afrikaans word for street extension	**Incorrect translation to English (from original data)**	**Correct translation to English (upon verification)**
Laan	Lane	Avenue
Weg	Way	Road

Source: Wright and Jacobs (2010)

In other cases the street extensions were just not supplied during registration. These extensions were added by looking up the specific street name within the suburb that was indicated. If only one street with the particular name (excluding extension) were present in the particular suburb, the extension was added to the name.

Several entries were found where the street address did not include the street number. Such entries could be verified in some cases by using the details (initials and surname) of the owners and the dates of registration to look up the street addresses in old telephone directories. The search for Cape Peninsula telephone books of the past 10 years was a real challenge. As part of this search, post offices and Telkom were contacted, posters asking the public for old phone books were placed at supermarkets and the landfill site in Bellville was visited numerous times in an attempt to recover these phone directories.

Eventually, all issues between 2000/2001 and 2006/2007 were obtained from a local paper recycling depot in Stikland, Bellville. The unclear and incomplete addresses could then be verified by comparing the registered details and telephone number of the owner or resident with that in the telephone directory of the corresponding or preceding calendar year in which the registration occurred. The success rate delivered by this process was 50% (29 out of 58 unclear or incomplete addresses could be verified) which is a similar figure to what was achieved by the same method during the “Hermanus pilot study”.

Finally, inclusions to and exclusions from the data set were made for the following entries:

- with an unclear or incomplete street address but of which the stand number was supplied were kept;
- of which the registered street address and suburb did not correspond was corrected where possible or else discarded; and
- of which the street address remained indefinite following the complete verification process were removed.

This gave a final set of entries with verified street addresses in three categories, as shown in Table 4.3 below.

Table 4.3: Categories of verified street addresses

<table>
<tr><th>Category description</th><th>Number of stands in category</th><th>Total</th></tr>
<tr><td>Good, usable data</td><td>4 165</td><td rowspan="3">4 241</td></tr>
<tr><td>Stands located in security complexes or private developments (sectional title stands)</td><td>61</td></tr>
<tr><td>Addresses with unknown street names or no street numbers but with plot numbers</td><td>15</td></tr>
<tr><td>Unknown or indefinite street addresses (discarded from data set)</td><td colspan="2">31</td></tr>
<tr><td>Total</td><td colspan="2">4 272</td></tr>
</table>

Source: Wright and Jacobs (2010)

The verified data summarised in Table 4.3, less those entries that have been discarded (which gave a final set of 4 241 entries in total), could now be evaluated further through geospatial analyses in order to obtain the spatial attributes of each. These attributes are required to link all the verified addresses with the water consumption data to be obtained from Swift and for a comparative analysis with AADD guidelines thereafter.

4.3 Geospatial analysis

Geo-spatial analysis is an approach towards applying statistical analysis and other informational techniques to geographically based data. Such analysis employs spatial software and analytical methods with geographic data sets, including geographic information systems (GIS). This analysis was done in two separate steps which are discussed in detail after this.

4.3.1 Myburgh (2009)

The final set of verified entries (4 241 in total) was passed on to Ms Erena Myburgh, a final year BEng student at Stellenbosch University in 2009. She used this data for her final year project entitled "Typology and spatial distribution of residential garden borehole users in the City of Cape Town" (Myburgh, 2009). The "spatial distribution" portion of the work by Myburgh (2009) was of great importance to this research, as the spatial attributes of all the verified addresses were required for further analysis. Various methods were assessed and applied in this work and essentially formed the first part of the geospatial analysis.

4.3.1.1 Initial attempts to generate spatial distribution

The author first looked into the possibility of using a global positioning system (GPS) receiver to generate the global coordinates of each address and configure a spatial plot by using a suitable GIS software package. Although the accuracy of consumer grade GPS receivers available nowadays was acceptable for these purposes, this idea was quickly abandoned, as it would have been a time consuming process considering the number of stands, even though each one would not necessarily have had to be visited.

Another method was to construct the unique Surveyor General's (SG) code for each verified address. SG codes are 21 digit keys that uniquely describe all cadastral land parcels in South Africa. This key contains specific sets of characters (21 in total) for the administrative district, town or allotment, parcel number and portion number of each stand. See Table 4.4 below for an example of how an SG 21 code is constructed.

Table 4.4: Constructed SG 21 code for Portion 97 of Farm 304, Plettenberg Bay

Administrative District (characters 1-4)	**Town or Allotment Area (characters 5-8)**	**Parcel Number (characters 9-16)**	**Portion Number (characters 17-21)**
Knysna	Plettenberg Bay	Erf/Farm No.	Portion No.
C039	0008	00000304	00097
C039 0008 00000304 00097			

As shown in Table 4.4 above, the SG 21 key of any land parcel can be constructed if sufficient information regarding the address is known, specifically the suburb and erf number. The SG codes generated in this manner could then be linked to the spatial attributes and water consumption data to be obtained from Swift for each stand.

The erf numbers of 2 794 addresses (out of 4 241) were captured electronically, while the balance (1 447 entries) were not supplied during registration. However, the SG codes of only 1 147 addresses (of the 2 794 entries with erf numbers) were successfully constructed with this method. The low success rate achieved can possibly be ascribed to several discrepancies related to suburb names. So it was decided not to persist with this method, as the results thereof would be suspect considering the poor results of the initial attempt.

4.3.1.2 Geocoding

In a final attempt Myburgh (2009) employed "geocoding" as a means to determine the positions of the verified addresses. The term "geocoding" refers to the process by which geographic data such as street addresses are converted to the associated geographic coordinates (i.e. latitude and longitude). Reverse geocoding is the opposite whereby textual locations such as street addresses are found from geographic coordinates. Various programmes, depending area and availability, can be used for this.

An address is "geocoded" basically through a process of "address interpolation" whereby certain elements of the address like the street number, street name, postal code and information about the location and direction of the specific road relative to the rest of the road network in the area. The “direction” of a road refers to the direction of ascending street numbers in that specific road. In spatial terms an addressed road network consist of various GIS layers that each contain different segments representing the street numbers, street names, directions of roads and information with regards to road intersections.

Consider the address of 124 Church Street (regardless in which town it is located) as a descriptive example. This address is situated in a segment, for instance a street block, of Church Street that has street numbers from 1 to 200 (for example) with an intersection exactly halfway along this road (for example). Typically all addresses with even street numbers are located on one side of a road and those with odd numbers on the opposite side. The geocoded position of 124 Church Street would therefore, through interpolation, be situated approximately a quarter of the distance between the intersection and the end of the road at street number 200 on the side of the road with even street numbers. The location will be mapped a certain distance from the centre line of the road taking into account the width of the road.

However, the geocoding process is not always as simple and uncomplicated (in terms of the accuracy of results) as explained with the above example. For instance the system assumes that all even street numbers are on one side of a road and the odd street numbers on the opposite side of it, although this is not always the case.

Another issue is the fact that all cadastral parcels are taken as being equally sized and evenly distributed, due to the interpolation function used with the geocoding process. This rarely occurs in reality, and all property boundaries have different shapes and sizes with uneven distances between them.

Some street addresses such as 24 Main Road and 24 S (South) Main Road are quite ambiguous. In this case the same coordinates will be returned for both addresses unless they are differentiated manually. Other difficulties that might occur are when a new street has not yet been added to the geographic system being used, or where streets have been renamed.

Various geocoding programs are available via the internet, some free of charge and other at a minimal tariff. However, such programs can only convert a single address at a time, which makes them less suitable for a data set comprising 4 241 entries as was the case with this study. This led to Myburgh (2009) writing a computer program that was used to convert verified addresses (in .xls format) to data basis files (.dbf format), which in turn were converted to a format consistent with the format used for internet programming namely .xml files. These files (in .xml format) were used to retrieve the coordinates from Google Maps using API files (file format that information is stored in Google). The X and Y coordinates of each address were subsequently retrieved in .dbf format.

Some errors occurred during the geocoding of the set of verified addresses using the program of Myburgh (2009). The main reasons for these discrepancies are as follows:

- Incomplete addresses e.g. no street number;
- Street names occurring more than once in the study area;
- Different spelling of street names (not necessarily incorrect); and
- Addresses such as corner of (c/o) Main Road and Church Street.

Consequently, 4 071 of the initial 4 241 addresses were successfully geocoded by Myburgh (2009), which returned the coordinates for each of these stands and enabled them to be plotted spatially (in GIS format) for further evaluation. The 170 entries that could not be geocoded with this program (due to the reasons given above) were not discarded, but kept separately to be added manually to the spatial plot.

4.3.2 Spatial analysis

The set of 4 071 successfully geocoded coordinates from Myburgh (2009) was obtained in January 2010 and plotted spatially with the assistance of Bester (2010) using a GIS software package named ArcGIS 10 from ESRI (Environmental Systems Research Institute) with the number “10” denoting the 10th edition of the program.

The spatial plot also included layers representing street numbers and street names as well as a layer of containing other property specific information such as erf numbers, SG 21 codes, cadastral layouts and stand sizes for the entire CCT area.

In addition to the 4 071 geocoded addresses, a further 126 stands (of the remaining 170 addresses which could not be geocoded) were added manually to the spatial plot. This gave the spatial distribution of 4 197 addresses in total, which were all yet to be checked to ensure that each entry fell within the cadastral boundary of the specific stand. The remaining 44 addresses which were not added are those that remained indefinite and could not be identified spatially or manually. This is summarised in Table 4.5 below.

Table 4.5: Categories of geocoded addresses

Category description	**Number of stands in category**
Successfully geocoded addresses	4 071
Addresses added manually to spatial plot	126
Subtotal	**4 197**
Indefinite addresses (not added)	44
Total	**4 241**

4.3.2.1 Spatial verification of data

Next the original plot of 4 197 geocoded addresses, hereafter only referred to as “data points”, were scrutinised, marked and moved manually, each point one by one. The plan was to ensure that the positions of each of the data points in the spatial plot fell within the cadastral boundaries of the stands it represented. This was required in order to do a spatial join between the data points and the layer containing property attributes, so as to obtain the SG 21 code and stand size for each.

The vast majority of the data points were positioned fairly close to their corresponding cadastral stands on the spatial plot, but very few of these data points were actually positioned within its boundaries. The screenshot shown in Figure 4.1 below is a good example of this and some other difficulties that were also encountered.

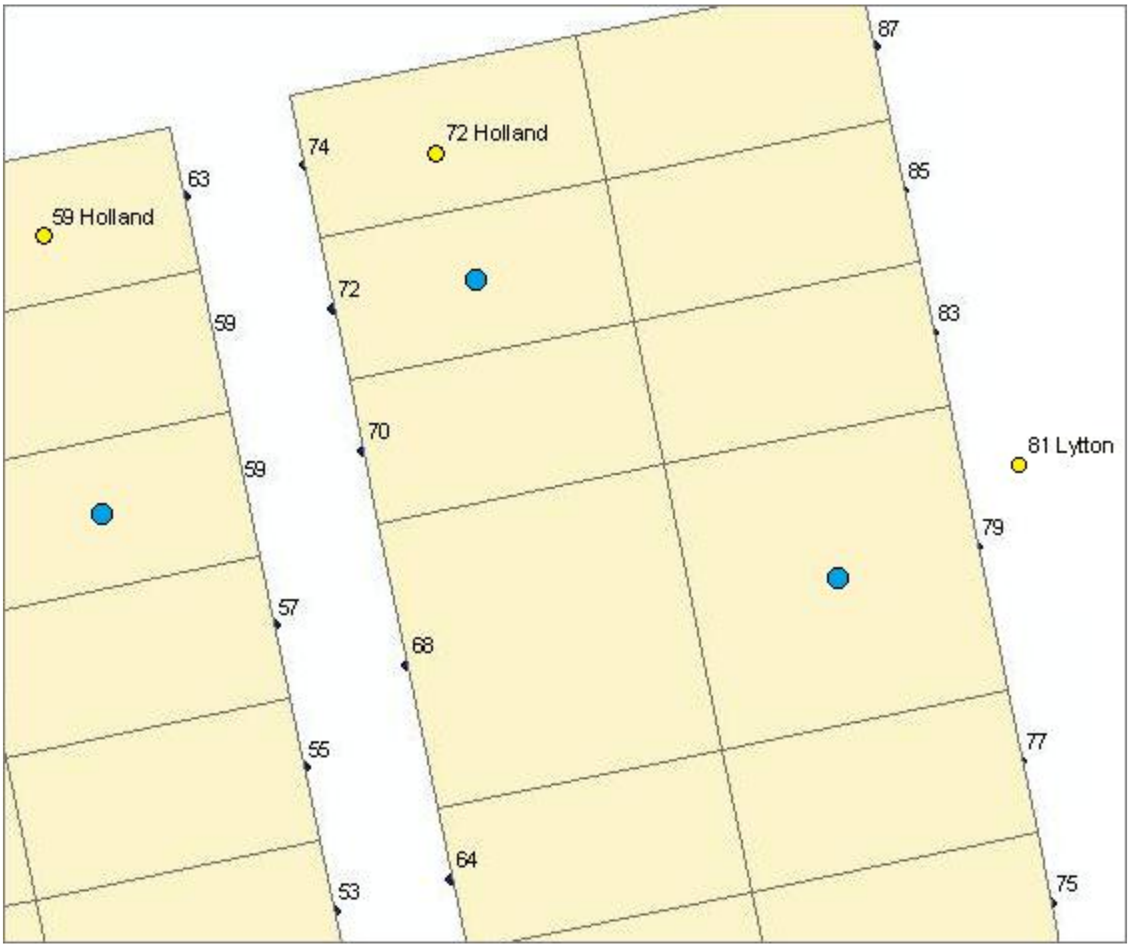

Figure 4.1: Screenshot of the spatial distribution of selected data points versus cadastral layout

The yellow dots in Figure 4.1 are the plotted data points of the geocoded coordinates, while the blue dots represent the true property attributes of these addresses.

The position of each yellow data point had to be checked and moved manually to within the cadastral boundaries of the address it represents. The following are good examples of some of the difficulties experienced during this process, as can be seen in Figure 4.1:

- A majority of the data points plotted were not positioned within the cadastral boundaries of the respective stands e.g. the data point for 72 Holland Street, is positioned at 74 Holland Street next to the actual address;

- Other data points plotted were positioned in the road of the street address they represent e.g. the data point for 81 Lytton Road is not positioned within any cadastral stand, but rather somewhere in Lytton Road;

- Some street numbers of the “street number” layer that was used are incorrect e.g. two stands with the number “59” along Holland Street are shown on the cadastral layout, although it is clear that the true street number of the upper one of these two stands should be “61” instead; and

- In some cases two or more stands were amalgamated into a single stand with one street number. However, discrepancies may exist between the actual street number of combined stands and the number given for it, as in the “street number” layer that was used e.g. 81 Lytton Road is an amalgamated stand (between street numbers 79 and 81) although the street number of this stand according to the cadastral layout is shown as “79”.

Some discrepancies not illustrated in Figure 4.1 are a result of stands situated on a corner bordering two roads, where the actual address was listed according to the one road but the spatial address contains the other road. However in such cases, being located on a corner shared by two roads, both “addresses” refer to the same cadastral stand regardless the street name, and therefore this did not pose a problem.

Other data points were initially plotted at the start or end of a road or the closest intersection, either because the specific street number could not be found along this road or due to the “street number” layer used not containing any street numbers. These are but some examples of the difficulties to be encountered during this process.

4.3.2.2 Verification of spatial data through visual inspection

Following the spatial verification process, all the data points were scrutinised, marked and moved (if required) through visual inspection to verify and confirm the address and position of each. These steps were all performed manually and simultaneously for each data point.

A data point was marked “1” if it appeared to be a single residential stand, the address was found spatially and it was successfully moved to within the cadastral boundaries of the address it represents. Google Street View (Google, 2011) was used extensively during this process to visually inspect properties as it provides panoramic views from positions along streets of many cities all over the world. In fact, without the Google (2011) “freeware” this process would have been a near impossible task from a practical point of view, as it probably would have required each of these stands to be physically visited in order to verify the address and position thereof.

The street number and position of each data point relative to its neighbouring stands could be confirmed with the aid of Google (2011). Street numbers appear either against house walls, front doors, on mail boxes or road kerbs. Some street numbers could not be verified as they were completely obscured by boundary walls, people, trees and parked cars, while others were unclear, not visible or totally absent. The front view of each stand was also checked using this tool and if it appeared to be a single residential stand it was kept for the time being and marked “1”.

Only stands that were undoubtedly used for non-residential purposes such as crèches, small businesses and shops operated from home or houses converted to offices were excluded from the category “1” group of stands. The true zoning of all these stands were to be confirmed again from Swift consumer data as a final check at a later stage. The data points marked “1” were each moved to within their cadastral boundaries on the spatial plot. In total 3 883 data points were initially marked “1” with the use of Google (2011).

The balance of 314 data points were all marked “2” and categorised based on the type of stand or the reason it was marked “2”. Of these, the single residential stands were categorised separately to be further examined later. The various categories and number of stands in each category are summarised in Table 4.6 below.

Table 4.6: Categories of data points initially marked “2”

Category description		Number of stands in category
Single residential stands	Incomplete/unknown addresses, but with erf numbers available	74
	Stands located in security complexes or private developments (sectional title stands)	32
	Addresses with non-numerical street numbers	32
	Unknown addresses (not found spatially)	28
	Stands located outside cadastral layout	25
	Subtotal	**191**
Other types of stands	Non-residential stands	49
	Duplicate entries	41
	Small-holdings	21
	Stands with multiple dwellings	9
	Vacant stands	3
	Subtotal	**123**
Total		**314**

The category descriptions of Table 4.6 are fairly self-explanatory and the reasons why the data points in the various categories did not form part of the set of entries that was initially marked “1” are obvious. Non-residential stands and residential stands with multiple dwellings on them clearly do not qualify as single residential stands, while duplicate entries and vacant stands were obviously also excluded.

Residential stands in Joostenbergvlakte, Kraaifontein and Penhill Estate, Eersterivier are really small-holdings, although used as mainly residential by the people who live here. These stands are all large-sized residential erven used in combination with private farming and other activities such as keeping of small stock and poultry, stables and kennels. It was therefore decided to exclude these entries (21 such stands) from the set of single residential stands marked “1”.

4.3.2.3 Other methods

The addresses of some single residential stands, although confirmed during the original verification process after the raw data was captured electronically, were not found spatially and thus categorised as “unknown”. Such stands, though the physical addresses were correct, gave dissimilar results when the geocoded coordinates were plotted spatially and were not even positioned anywhere close to the street addresses they represent, many of which outside the actual suburb or region.

However these data points and those in the other single-residential-stand categories of Table 4.6 were not removed, simply because they could not be confirmed spatially the first time around. Instead, other methods were applied in an attempt to trace these addresses (191 such data points in total), so that they too could form part of the final set of data points verified and confirmed spatially. Many of these could be “saved” through one of two further methods that were used.

The first method was to manually search for the erf numbers, street names and street addresses of such stands from the list of attributes that forms part of the property layer used with the spatial plot. This layer contains the property attributes of all the stands within the cadastral layout, and is fully independent of the spatial layers for the plotted street names and street numbers.

Many discrepancies exist in terms of the spelling and translation (between English and Afrikaans) of some street names in the property layer. For example “Church Street” might have been recorded in the property layer as “Kerk Straat” or the other way around. The format and extensions of several listed street addresses differed from what was verified previously as being correct according to other sources.

Other inconsistencies existed in terms of the listed street numbers of some addresses in the property layer e.g. number “22A”, “22-24” or “24” in place of a street number originally confirmed only as “22”. Stands with incomplete or unknown addresses were also searched based on their erf numbers (if available) in an attempt to link these addresses to their respective cadastral stands and property attributes spatially.

The second method, which also required a manual search, one address at a time, was much simpler and involved the use of a very convenient on-line tool on the CCT's official website (CCT, 2011) that can be used to look up property details. This tool is based on the "General Valuation Roll" (GVR) for all listed properties that fall within the jurisdictional areas of the CCT. The GVR data base may be accessed by anyone to confirm the details and obtain the CCT's valuation of a specific property. The version used for this purpose was for the valuation period between 1 July 2007 and 30 June 2011, although this did not really matter, since the property details were required and not the valuation.

In order to search for a property with this tool using the street address, both the street name and street number can be typed in and searched. The correct spelling of the street name, according to the CCT's data base, is obviously required. One can also do a random search by typing in the street name only, preceded and followed by the percentage (%) symbol, e.g. "%Church%" which would then retrieve all the streets with the name "Church" on the data base, or within a specific area if a suburb name was also supplied.

Properties can also be searched by erf number using this tool. This option only allows the erf number to be typed in, and a suburb name cannot be supplied in conjunction with it. A list is retrieved showing all the properties with this erf number, that the user must then look through to find the address of the specific property being searched for. Sectional title properties can also be looked up by supplying the scheme name and unit number.

The above two methods were used to search and verify the details and subsequently the spatial position of some of the data points for single residential stands marked "2" (191 such data points in total), that could not be confirmed previously through either spatial verification or visual inspection (refer to Table 4.6). The data points of stands that could not be found or clearly identified using these methods and which remained unknown following this process were finally discarded from the selection of verified addresses to ensure that the final data set contain only discrete records.

A summary of the data points in the “single residential stand” categories of Table 4.6 that were “saved” during this process (167 out of 191 data points in total) is shown in Table 4.7 below.

Table 4.7: Summary of “saved” data points initially marked “2”

Category description	Original number of stands in category	Number of “saved” stands in category
Incomplete/unknown addresses but with erf numbers available	74	68
Stands located in security complexes or private developments (sectional title stands)	32	26
Addresses with non-numerical street numbers	32	32
Unknown addresses (not found spatially)	28	16
Stands located outside cadastral layout	25	25
Total	**191**	**167**

The “saved” data points shown in Table 4.7 were then added to those initially marked “1” (3 883 data points in total), resulting in a final set of data points verified in terms of address and location (4 050 data points in total). However, stands located outside the cadastral layout of the property layer used could not be added spatially, and were therefore listed separately in .xls format (25 such data points). This effectively gave the final spatial plot consisting of 4 025 data points as shown in Table 4.8.

Table 4.8: Final set of verified data points

Category description	Number of data points
Set of data points initially marked “1”	3 883
“Saved” data points initially marked “2”	167
Final set of verified data points	**4 050**
Stands located outside available cadastral layout	25
Final spatial plot of verified data points	**4 025**

4.4 Capturing unique stand attributes

Once the final set of verified data points was confirmed (4 050 in total), attributes such as stand size and the unique SG 21 cadastral code of each stand had to be captured. The stand sizes were required directly for the purposes of the comparative analysis to follow, while the SG 21 codes were used to link the stands to Swift records and consumer information in order to obtain the water consumption data for each.

The data points forming part of the final spatial plot (4 025 in total) were joined with the property layer containing the stand attributes. The spatial join was done with the function on ArcGIS 10 whereby the attributes of a primary layer are joined with the attributes of a secondary layer based on each record in the primary layer of which the shape is located within a shape of any record in the secondary layer. In this case the primary shapes were those of the verified data points, which were joined with the closed polygons of the cadastral layout they are located within and which represent the property layer containing stand attributes.

The primary records and attributes of the associated secondary records could therefore be joined through this process to form a new spatial layer comprising all the verified data points with combined attributes. All records of the new spatial layer (4 025 in total) were exported to .xls format. The attributes of stands located outside the cadastral layout of the property layer (25 in total) could obviously not be joined spatially and instead were obtained with the assistance of Bester (2012) using other GIS sources. The attributes for these stands were also listed in .xls format.

Subsequently a final list of all verified data points (4 050 in total) were compiled in .xls format with full address details, SG 21 codes, stand sizes and global coordinates for each stand. As a final check, the column containing the SG 21 codes in the .xls spreadsheet was checked for duplicate SG 21 codes by using the “remove duplicate entries” function in Microsoft Excel. This, however, did not yield any SG 21 codes occurring more than once, which ultimately presented a final set of 4 050 verified addresses with stand attributes (of residential properties with GAPs), which were to be used in the comparative analysis.

4.5 Spatial distribution of verified data points

Underground geological layers largely determine the availability and accessibility of groundwater for abstraction. The underlying geology of developed areas in the Cape Peninsula consists mostly of sediment and shale from the Malmesbury Group and quaternary sands that are exceptionally suitable to serve as aquifers, while the more impermeable rock structures such as that belonging to the Table Mountain Group and Cape granite coincide with the higher lying areas as shown in Figure 4.2 below.

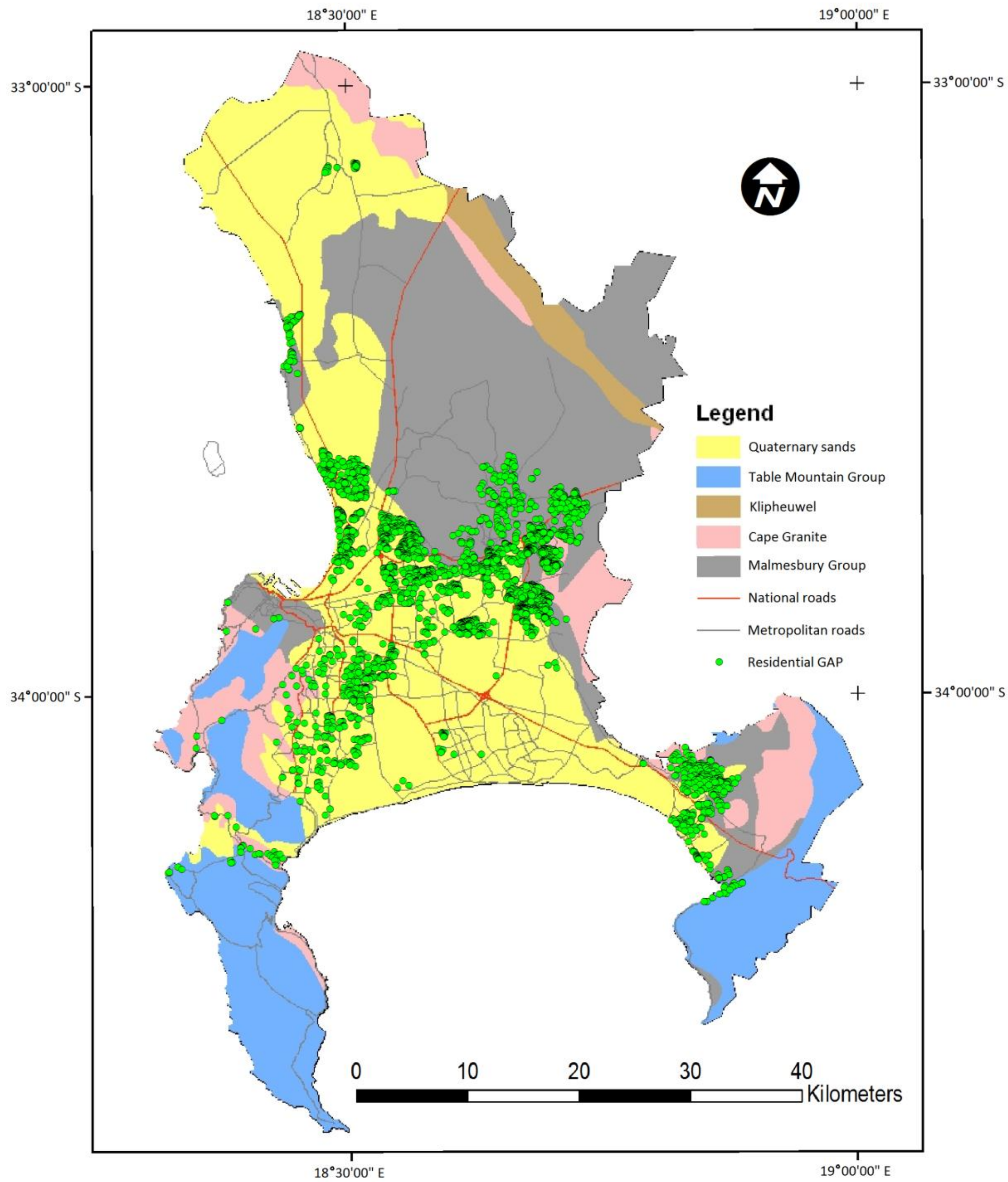

Figure 4.2: Spatial distribution of final set of residential GAPs against the geological layout of the Cape Peninsula

The final set of verified data points, representing residential stands with private GAPs, was plotted on the geological layout of the Cape Peninsula obtained from CG (2013) and presented in Figure 2.9. The resultant spatial distribution of the residential GAPs is shown in Figure 4.2.

It is clear from Figure 4.2 that the absolute majority of GAPs are situated in areas with underlying geological structures of sand and sedimentary material which corresponds with the CFAU (refer to Figure 2.10) and that has significant groundwater exploitation potential.

It is also evident that the GAPs are mainly grouped in the northern suburbs, the Helderberg area and Athlone. The rest are scattered around the southern suburbs and elsewhere, with some also situated on the fringes of the CCT jurisdictional area in Fish Hoek, Melkbosstrand and Atlantis.

5. Selection and classification of data

5.1 Available water consumption data

Recent water consumption data, i.e. AADD values, of all the stands in the final set of verified addresses is required in order to assess the typology of GAP users and the water demand at residential stands with GAPs identified with this research.

The AADD values required for this analysis were obtained from the CCT Swift data with the assistance of Fair (2012). Swift is industry standard software used to calculate water demand related statistics, perform water balance simulations and for tariff analysis and revenue enhancement. CCT Swift data includes the water consumption records of stands based on the data extracted by the CCT from their SAP (Systems Applications and Products) billing system. SAP is software that provides the capability to manage financial, asset and cost accounting.

This extract generates separate files for properties, consumers, accounts, meters and meter readings which have to be linked together before any of the information can be used. This is by no means a straight-forward task, considering the vast number of records (there are more than 700 000 stands in the CCT area) and the complexity of some of the linking that is required.

Another complication is the fact that meter readings are in raw format that includes erroneous data such as inaccurate entries, unlikely estimates and incorrect handling of clock-overs, to name but a few. Irregularities in water meter readings include sudden drops in readings when a meter is being replaced, spikes or dips in water consumption records and unrealistically high or low readings. Possible causes of such discrepancies are faulty meters and data capturing errors (Jacobs and Fair, 2012).

The CCT therefore appointed a specialist consultant (i.e. GLS Consulting) to process the CCT information in Swift between 2010 and 2011 only. No consumer information was available for the CCT prior to this, due to problems experienced with the extraction routine developed by CCT, while no consultants have been appointed to update the Swift data since this time either (Fair, 2012).

Swift uses 12 months' data prior to the date it is extracted to calculate the AADD values for stands. These calculations are based on the monthly water meter readings and thus exclude any losses in the water distribution network. The AADD values used for the purposes of this research are for the year that ended 30 April 2011 and were calculated based on the availability of data for a minimum period of 12 months preceding this date.

According to Fair (2012), at the time this was the only data available in Swift applicable to this research, which made it the latest and best available data that could be found for this study. No data was obtained directly from the CCT for these purposes, as it is unprocessed and not in a workable format.

5.2 Stand size classes

The comparative analysis is based on residential water demand (i.e. AADD) plotted against stand size as single variable. Swift lists only the stand size class of residential stands (in multiples of 500 m^2 up to 2 000 m^2) and does not give the exact stand size for any records. Therefore the property sizes determined spatially would be used without amendment for the purposes of the comparative analysis.

The next step was to determine the stand size classes to be used in the comparative analysis, where the frequency distribution of the average water demand for all stands in each class will be plotted against various AADD guidelines for easy comparison. In order to construct a frequency distribution, the range of the data must be divided into intervals, usually called class intervals or bins. The bins should ideally be of equal width to enhance the visual information of the frequency distribution.

However, some thought must be given to selecting the number of bins so that a reasonable display can be developed. The number of bins depends on the number of observations and the amount of scatter or dispersion in the data. A frequency distribution that uses either too few or too many bins will not be informative. Some literature referred to notes that choosing a number of bins roughly equal to the square root of the number of observations often works well in practice. This would be impractical in this case, considering the distribution of more than 4 000 points (the square root of 4 000 equals roughly 63). According to Montgomery and Runger (2003), in most cases between 5 and 20 bins is satisfactory, regardless of the sample size.

The AADD guidelines to be used for comparison are the same as those used in the "Hermanus pilot study" namely the "Red Book" (CSIR, 2003), Jacobs *et al*. (2004) and Van Zyl *et al*. (2008). The stand area envelope intended for use with the comparative analysis should, therefore, fall within the valid stand size range of each of these guidelines, preferably with a common upper and lower stand size limit so that the same number of stand size classes is used for all three comparative analyses.

The "Red Book" guideline curves were developed for stand areas up to 2 000 m^2, whilst those of Van Zyl *et al*. (2008) have a higher boundary of 4 000 m^2. The "Red Book" curves are linear and can easily be extrapolated for stand areas up to 4 000 m^2 to match this. However, the guideline curves presented by Jacobs *et al*. (2004) were based on actual data with stand size values up to a maximum of 2 050 m^2, only and therefore cannot be extended simply by extrapolation. The valid stand size ranges that each of these three sets of guidelines are based on are shown in Table 5.1 below.

Table 5.1: Valid stand size ranges of water demand guidelines to be used in the comparative analysis of full-scale application

Particulars of water demand guidelines (author(s), year)	**Valid stand size range**	
	Lower stand size limit	**Upper stand size limit**
"Red Book" (CSIR, 2003)	300	2 000
Jacobs *et al*. (2004)	50	2 050
Van Zyl *et al*. (2008)	100	4 000

The valid stand size range of Jacobs *et al*. (2004) was divided into 20 equal stand size classes when these guidelines were originally derived. Each stand size class has a bound of 100 m^2 ranging from 100 m^2 (50 - 150 m^2) set as the lower limit to an upper limit of 2 000 m^2 (1 950 - 2 050 m^2).

In comparison, the guidelines by Van Zyl *et al*. (2008) were developed using dissimilar stand size classes, with bounds varying between 250 m^2 and 1 000 m^2 each. This guideline is applicable to stand areas of 100 m^2 minimum up to a maximum of 4 000 m^2 as shown in Table 5.1.

Based on this the following was decided with regards to the stand size range and the number of classes to be used for the comparative analysis:

- The same stand size range to be used for all three analyses;
- Lower limit of stand size range to be 150 m^2;
- Upper limit of stand size range to be 2 050 m^2;
- “Red Book” guideline curves to be extrapolated to include all stand areas from 150 m^2 to 2 050 m^2 - i.e. 150 m^2 negatively from original lower limit of 300 m^2 and 50 m^2 positively from original upper limit of 2 000 m^2; and
- The stand size range to be divided into 19 equal classes each with a bound of 100 m^2 ranging from 200 m^2 (150 - 250 m^2) to 2 000 m^2 (1 950 - 2 050 m^2) similar to that of Jacobs *et al*. (2004).

The above classification thus provides for a stand size range (from 150 m^2 to 2 050 m^2) comprising 19 equal stand size classes. The 19 “bins” proposed herewith fall within the maximum number of 20 “bins” as suggested by Montgomery and Runger (2003) for frequency distributions. This envelope also ensures that common upper and lower limits will be used for all three of the comparative analyses.

5.3 Single residential stand selection

The Swift data was obtained for all stands in the CCT area for the abovementioned period (12 months prior to 30 April 2011) and exported to .xls format. The records of the 4 050 stands that formed part of the final set of verified addresses were extracted from the Swift data by using the unique SG 21 codes to look up the stands. The records of 4 035 stands could be extracted in this way. The SG 21 codes of the remaining 15 addresses could not be found in the Swift data.

A stringent query, partly adopted from Jacobs *et al*. (2004), was executed to exclusively select only extracted records that fulfilled certain criteria pertaining to the Swift data. This was to ensure that a fully discrete set of records is used in the comparative analysis to give a true and accurate assessment. The query was applied so as to filter through the extracted data and keep only those records of stands with the following attributes:

- Land use category is single residential;
- Stand AADD value is greater than zero;
- Uniquely assigned to a stand (one meter per stand and vice versa);
- Stand size is larger than 150 m^2 and smaller than 2 050 m^2; and
- Not a "large water user" (< 20 kl/d).

All the verified addresses were previously confirmed as single residential stands through visual inspection using Google (2011). However, the extracted records were again scrutinised to confirm the single residential status of every stand based on the "land use" as listed in Swift. This process helped to identify another 25 non-residential stands, which were then removed from the set of extracted data, as only single residential stands were to form part of the comparative analysis.

Swift does not flag vacant stands per se, although records with stand AADD values equalling zero (i.e. 0.000 kl/d) may represent such stands among others. A total of 24 records with AADD values of zero were found in the extracted data and subsequently removed from the final selection. Any vacant stands that might have existed in the original registration data had already been removed through the visual inspection process completed earlier (refer to Table 4.6).

Jacobs *et al*. (2004) used the "improvement value on the property" as indicator to distinguish between vacant and non-vacant stands where an "improvement value" larger than zero represents a non-vacant stand. However the "improvement value" of stands is no longer maintained in the financial systems of the CCT and only the estimated total value of stands are recorded (Fair, 2012). It is therefore no longer a valid indicator of stand occupancy, and could not be used.

Furthermore, the extracted data contained 109 records of stands with more than one water meter per stand or stands that share a single water meter with other stands. These records are not each uniquely assigned to a single stand and were also removed from the final selection. No records of "large water users" (i.e. > 20 kl/d) were found in the set of extracted data.

The records were also filtered based on stand size, during which a further 112 records of stands larger than 2 050 m^2 and one stand with erf size less than 150 m^2 were removed from the set of extracted data, so that all the stands in the final selection fell within the stand size range determined earlier for use with the comparative analysis.

Lastly, the remaining records were filtered to remove any duplicates from the final selection but none were found. In total, 286 records did not comply with the selection criteria and were subsequently removed during this process. A summary of all the records removed is given in Table 5.2 below.

Table 5.2: Summary of records removed by application of selection criteria

Record description	**Number of records**
Stand size larger than 2 050 m^2	112
Not uniquely assigned to a stand	109
Non-residential stands	25
Stand AADD value equals zero	24
Not found on Swift data base	15
Stand size smaller than 150 m^2	1
"Large water users"	0
Duplicates	0
Total	**286**

This reduced the set of data that fulfilled the selection criteria to a final total of 3 764 records, as shown in Table 5.3. The records selected by means of this query therefore include only non-vacant single residential stands that fall within the said stand size range and where water is used from a single metered water connection to the pressurised municipal supply system.

Table 5.3: Summary of final data set upon selection process

Record description	Number of records
Complied with all selection criteria	3 764
Removed due to non-compliance	286
Total	**4 050**

It is possible that the selection of records from the Swift data includes a few users that do not meet the desired specification due to erroneous entries, and stands that may have been unoccupied for a period during the 12 months that the AADD calculation was based on. These scenarios are not reflected or flagged in Swift. The effect on the results is, however, considered to be insignificant and the records of the 3 764 stands selected herewith will be used in the comparative analysis.

6. Results of comparative analysis

6.1 Presentation of results

The actual water demand of all single residential stands identified positively by the selection process could now be plotted against the different stand size classes and the three separate AADD guidelines it is being compared to. This will form the basis of the comparative analysis.

The results of the comparative analysis will be presented by means of a frequency distribution, as this better illustrates contrast and disparity. A frequency distribution is an arrangement (by table or graph) of the values that one or more variables take in a sample. Each entry contains the frequency or count of the occurrences of values within a particular group or interval, in this case a stand size class. This way the distribution of all the values in a sample is summarised.

Frequency histograms were used for the comparative analysis of the data from the "Hermanus pilot study" and were also considered for use with the full-scale application of the Cape Peninsula data. However, the horizontal graph width of a histogram used to compare multiple sets of data in the number of stand size intervals determined earlier is too wide to be presented here and it was decided to use a frequency polygon instead.

A frequency polygon is not a statistical fit but presents data in a graph that uses plotted values as markers connected by straight lines to better illustrate a series of frequencies, rather than a trend. This makes it very suitable for the purposes of the comparative analysis and will therefore be used.

6.2 Comparative analysis

The AADD values (l/d) and stand sizes (m^2) of the selected stands were tabled in .xls format to facilitate further processing. A scatter plot of the AADD values versus stand size of all 3 764 records is shown in Figure 6.1 hereafter.

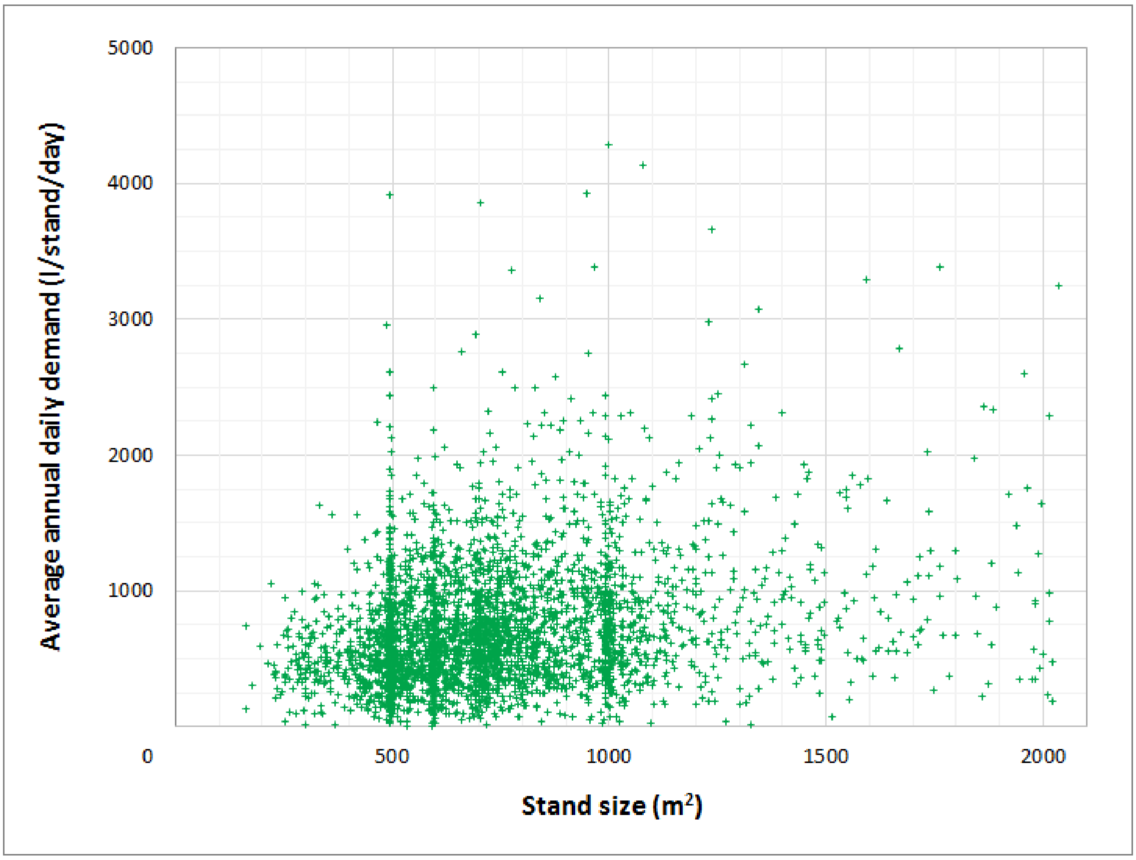

Figure 6.1: Average daily water demand of residential stands with GAPs in Cape Peninsula versus stand size

An interesting observation first up, although of no statistical significance in these terms, is the number of stands clustered vertically above and around the 500 m^2, 600 m^2, 700 m^2 and 1 000 m^2 vertical gridlines of Figure 6.1. This feature will however not be investigated any further during this study.

The actual average stand size for each stand size class was calculated and found to be within 7% of the centre value for 17 of the 19 classes. The spread of the 3 764 selected records across the 19 stand size classes and the mean AADD value of each class are presented in Table 6.1 below.

Table 6.1: Sample size and mean AADD per stand size class

Stand size class (m^2)	Sample size (no.)	Percentage of total sample size (%)	Mean AADD (l/stand/day)
200	17	0.45	444.1
300	104	2.76	501.5
400	172	4.57	528.5
500	822	21.84	607.6
600	609	16.18	664.0
700	650	17.27	710.6
800	355	9.43	769.7
900	254	6.75	852.6
1 000	379	10.07	793.7
1 100	126	3.35	818.2
1 200	73	1.94	1 040.5
1 300	49	1.30	1 036.6
1 400	36	0.95	956.6
1 500	34	0.90	906.3
1 600	23	0.61	1 037.5
1 700	21	0.56	983.9
1 800	10	0.27	1 256.9
1 900	12	0.32	1 106.8
2 000	18	0.48	1 085.2
Total	3 764	100	

It is clear from Table 6.1 that a majority of the samples are spread across the stand size classes between 500 m^2 and 1 000 m^2 with more than 80% (i.e. 3 069 records) falling within these 6 consecutive classes.

The mean AADD values for the entire stand size range as shown in Table 6.1 were plotted against the centre values of all 19 stand size classes and are presented graphically through a frequency polygon in Figure 6.2 below.

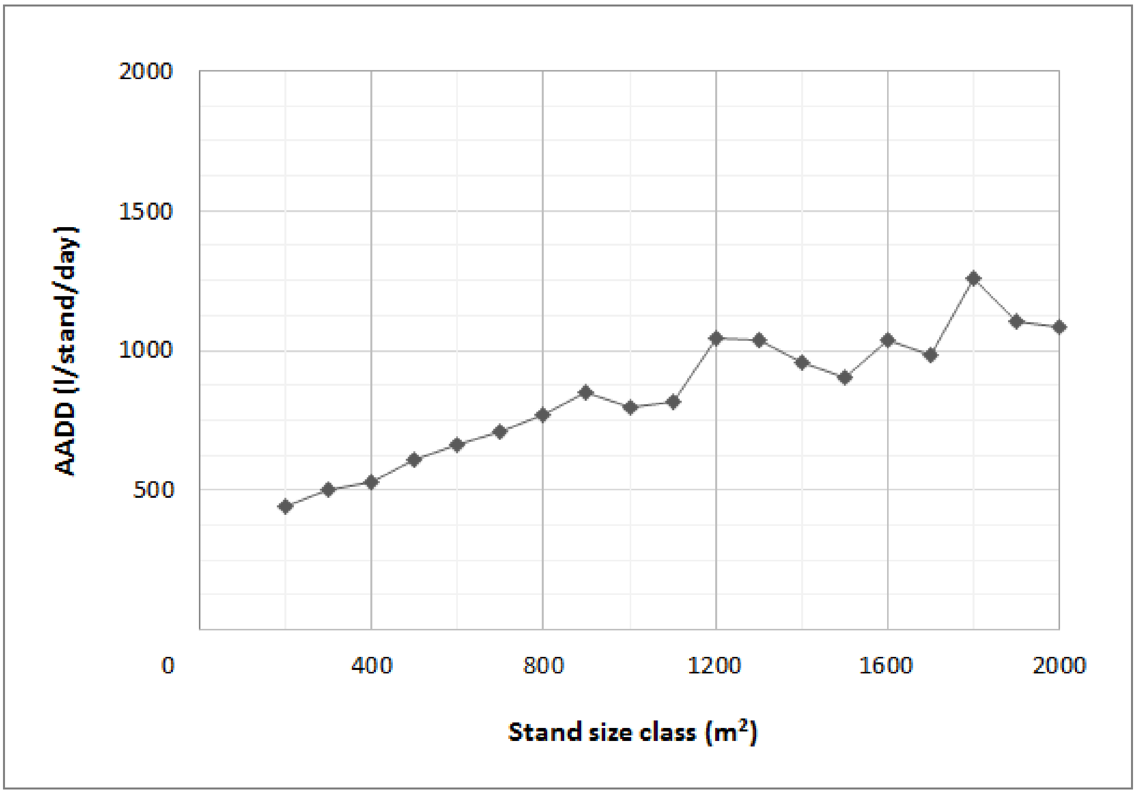

Figure 6.2: Frequency polygon of mean AADD values for all stand size classes

The plotted markers in Figure 6.2 present the mean AADD values of each stand size class. The count of records in the 200 m^2 class and those in the 1 400 m^2 to 2 000 m^2 size range (i.e. 8 stand size classes in total) are each less than 1% of the total sample size (see Table 6.1) and together make up less than 5% (i.e. 171 records) of the 3 764 selected records.

The number of records available in each of these 8 size categories is considered too few, and they will therefore be excluded for the purposes of the comparative analysis (171 records in total). The remaining 11 stand size classes in the 300 m^2 to 1 300 m^2 size range contain a total of 3 593 records (i.e. more than 95%), which will now be used for comparison with three separate AADD guidelines.

The comparative analysis of the Cape Peninsula data is a full-scale application of the method tested earlier with the "Hermanus pilot study", although frequency polygons will be used to present the results instead of histograms.

6.2.1 Red Book (CSIR, 2003)

The water demand of the 11 stand size classes being considered is first compared to the "Red Book" AADD guideline (CSIR, 2003). The mean AADD values of the selected size classes are tabled with the AADDs of the corresponding stand sizes for both the upper and lower limits of the "Red Book" as shown in Table 6.2 below.

Table 6.2: Mean AADD per size class versus AADDs for corresponding stand sizes as per "Red Book" guideline

Stand size class (m^2)	**Mean AADD (l/stand/day)**	**"Red Book" guideline**	
		Lower limit (l/stand/day)	**Upper limit (l/stand/day)**
300	501.5	600	1 200
400	528.5	600	1 200
500	607.6	600	1 200
600	664.0	600	1 200
700	710.6	707.1	1 360.7
800	769.7	814.3	1 521.4
900	852.6	921.4	1 682.1
1 000	793.7	1 028.6	1 842.9
1 100	818.2	1 135.7	2 003.6
1 200	1 040.5	1 242.9	2 164.3
1 300	1 036.6	1 350.0	2 325.0

It is clear from Table 6.2 that the mean AADD values are considerably smaller than those of the upper limit for all the stand size classes considered. The data compares more favourably with the lower limit AADDs and is marginally higher only for the 500 m^2 to 700 m^2 size classes.

The data in Table 6.2 is presented graphically, by means of frequency polygons of the AADD values per size class, for better illustration in Figure 6.3.

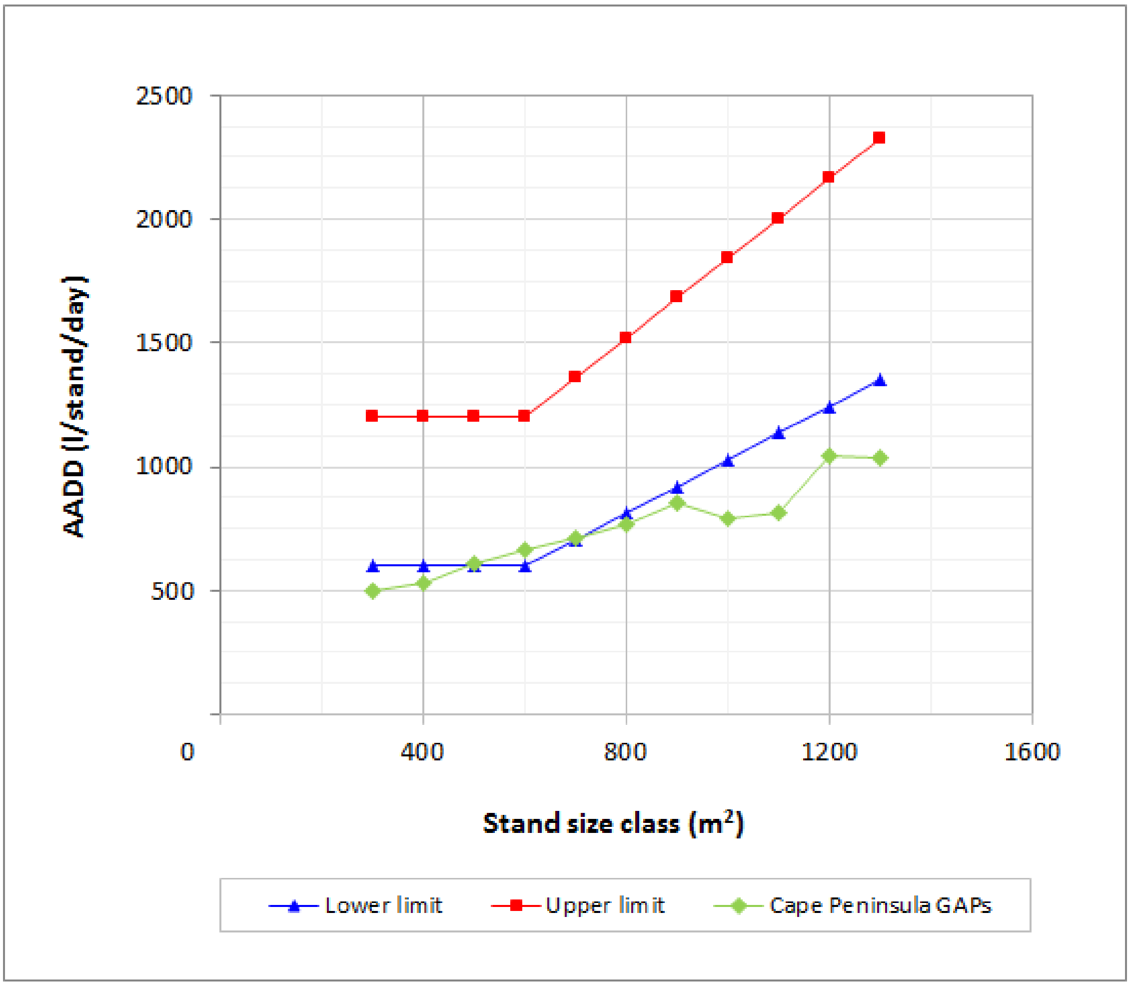

Figure 6.3: Frequency polygons of mean AADD per size class versus AADDs for corresponding stand sizes as in "Red Book" guideline

The frequency polygons in Figure 6.3 give a good visual impression of the close comparison between the mean AADD values and the lower limit of the "Red Book" guideline, particularly up to the 900 m^2 stand size class. Consequently, the mean AADDs are significantly lower than the upper limit of the guideline envelope.

6.2.2 Jacobs *et al*. (2004)

The mean AADD values of the selected stand size classes are next compared with the guideline curves of Jacobs *et al*. (2004). The Cape Peninsula is situated in a winter rainfall region on the south western coast of South Africa and thus the guideline curve for “coastal winter rainfall regions” was used for the comparative analysis, similar to that used in the “Hermanus pilot study". The data is summarised with the guideline AADDs for the corresponding stand sizes as shown in Table 6.3 below.

Table 6.3: Mean AADD per size class versus AADDs for corresponding stand sizes according to Jacobs *et al*. (2004)

Stand size class (m^2)	Mean AADD (l/stand/day)	Jacobs *et al*. (2004) guideline		
		Guideline curve (l/stand/day)	Lower envelope (l/stand/day)	Upper envelope (l/stand/day)
300	501.5	618.8	410	882.8
400	528.5	729.4	480	993.4
500	607.6	840.0	550	1 104.0
600	664.0	950.6	620	1 214.6
700	710.6	1 061.2	690	1 325.2
800	769.7	1 171.8	760	1 435.8
900	852.6	1 251.3	830	1 546.4
1 000	793.7	1 307.5	900	1 657.0
1 100	818.2	1 363.8	970	1 766.8
1 200	1 040.5	1 420.0	1 040	1 823.0
1 300	1 036.6	1 476.3	1 110	1 879.3

The mean AADD values in Table 6.3 compare well with the lower envelope curve of the guideline for the entire stand size range and are marginally higher for size classes up to the 900 m^2. The mean AADDs are considerably smaller than those suggested by the guideline curve for each of the corresponding stand sizes.

The data in Table 6.3 is presented graphically, by means of frequency polygons of the AADD values per size class, for better illustration in Figure 6.4.

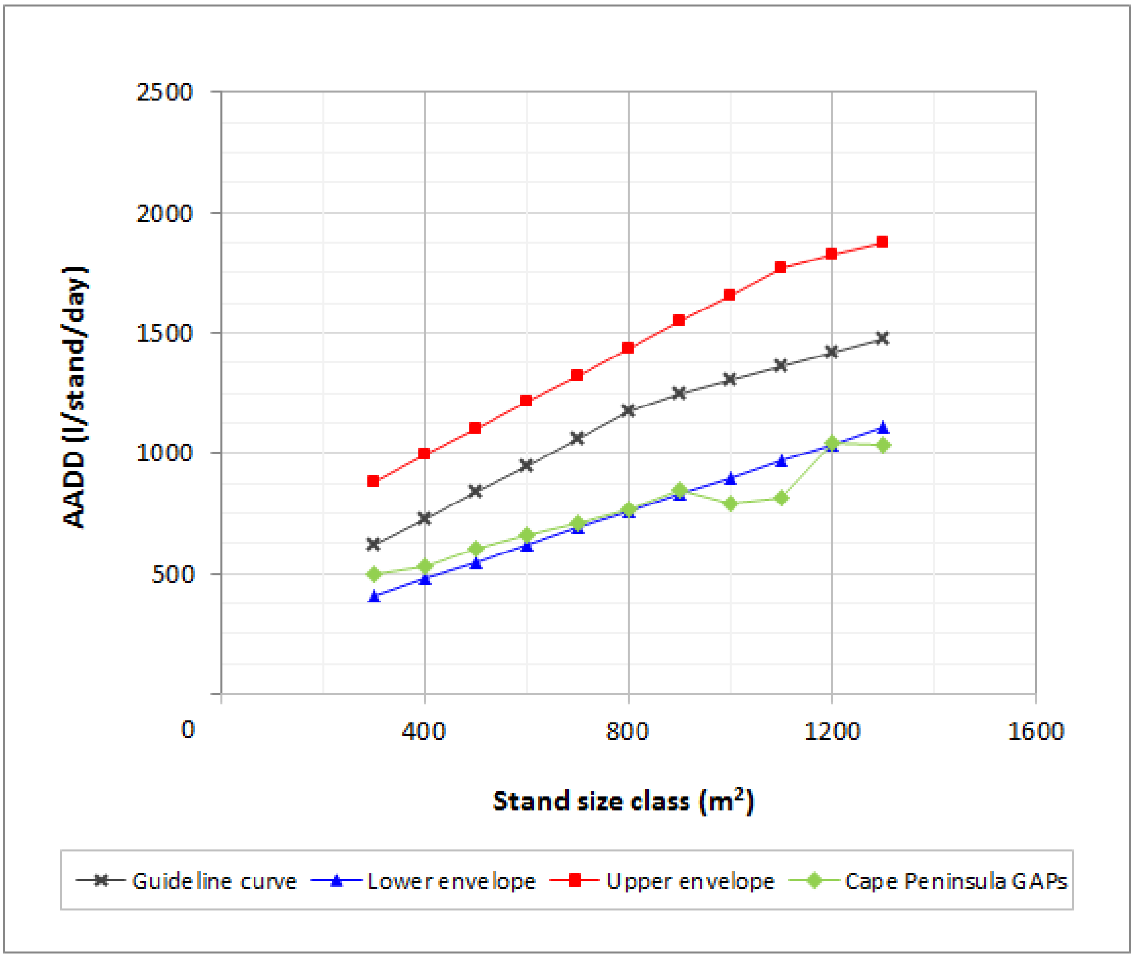

Figure 6.4: Frequency polygons of mean AADD per size class versus AADDs for corresponding stand sizes according to Jacobs *et al*. (2004)

The frequency polygons in Figure 6.4 give a good visual impression of the close comparison between the mean AADD values and the lower envelope of the guideline, particularly for stand size classes up to the 900 m^2. It is therefore clear that the mean AADDs of the entire size range are considerably lower than the corresponding AADD values given by the guideline curve.

6.2.3 Van Zyl *et al*. (2008)

Finally, the mean AADD values of the 11 stand size classes that were selected for the comparative analyses are plotted against the AADDs for the corresponding stand sizes from the guideline curves presented by Van Zyl *et al*. (2008). This data is summarised in Table 6.4 below.

Table 6.4: Mean AADD per size class versus AADDs for corresponding stand sizes according to Van Zyl *et al*. (2008)

Stand size class (m^2)	Mean AADD (l/stand/day)	Van Zyl *et al*. (2008) guideline	
		Guideline curve (l/stand/day)	5% confidence limit (l/stand/day)
300	501.5	1 087.7	528.6
400	528.5	1 184.7	575.8
500	607.6	1 265.8	615.2
600	664.0	1 336.3	649.4
700	710.6	1 398.9	679.9
800	769.7	1 455.5	707.4
900	852.6	1 507.3	732.5
1 000	793.7	1 555.2	755.8
1 100	818.2	1 599.9	777.5
1 200	1 040.5	1 641.7	797.9
1 300	1 036.6	1 681.2	817.1

The mean AADD values in Table 6.4 compares well with that of the 5% confidence limit which forms the lower boundary of the 95% (+) and 5% (-) confidence envelope of the guideline. Similar to the comparative analysis with Jacobs *et al*. (2004), the mean AADDs are noticeably smaller than those presented by the main guideline curve for all the selected stand size intervals, many of which are less than half the suggested AADD value.

The data in Table 6.4 is presented graphically by means of frequency polygons of the AADD values per size class for better illustration in Figure 6.5.

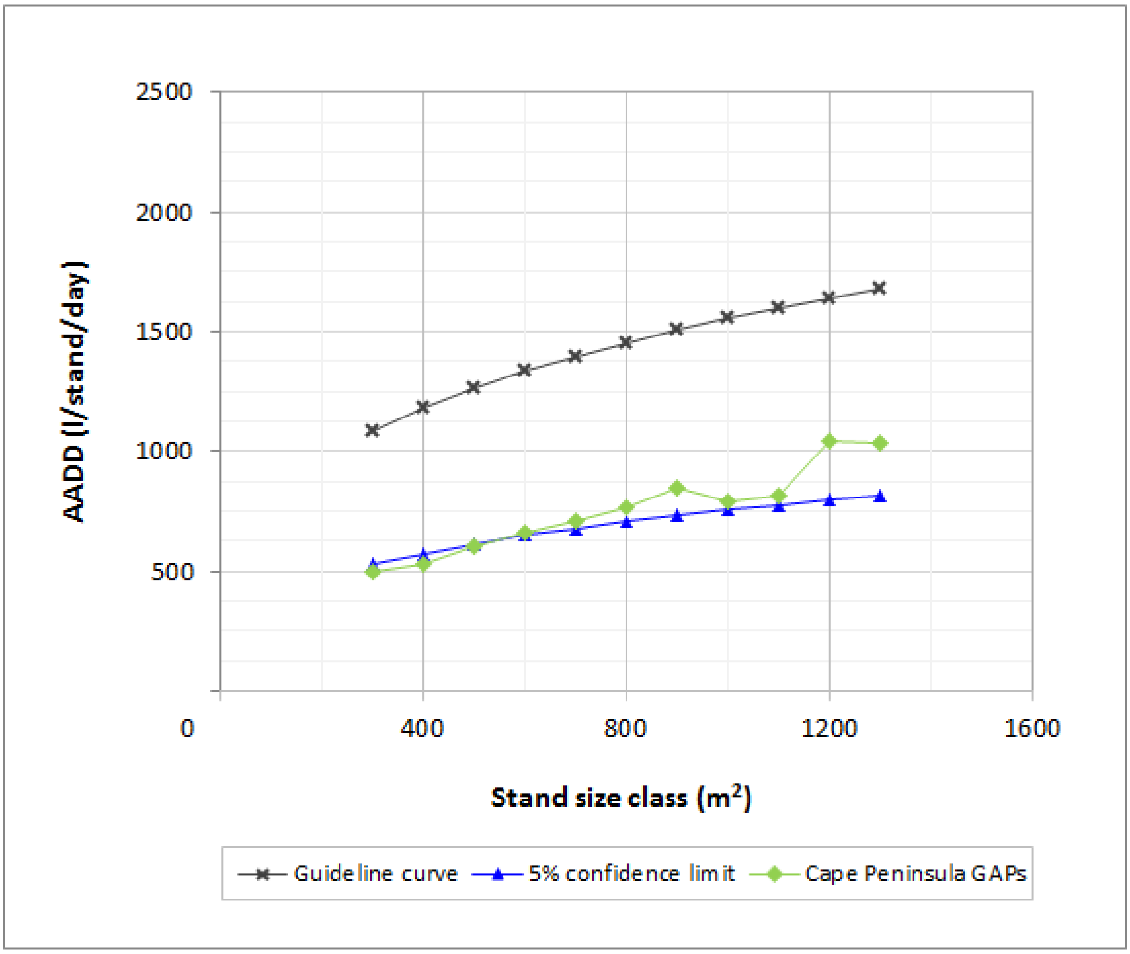

Figure 6.5: Frequency polygons of mean AADD per size class versus AADDs for corresponding stand sizes according to Van Zyl *et al*. (2008)

The frequency polygons in Figure 6.5 illustrate the relatively good comparison of the mean AADD values with the 5% confidence limit, especially for the first 9 size classes (i.e. up to 1 100 m^2) of the stand size range. Again, similar to the comparison of this data with the Jacobs *et al*. (2004) guideline, the mean AADDs of all 11 size classes are visibly much lower than those suggested by the guideline curve.

7. Discussion of results

7.1 Red Book (CSIR, 2003)

The comparison of the data with the “Red Book” AADD guideline (CSIR, 2003) as per Figure 6.3 shows that the mean AADD values of the selected size classes are significantly lower than the upper limit of the guideline envelope and form a better comparison with the lower limit of the guideline.

However, various studies have labelled the “Red Book” model as too conservative in the past. According to Husselmann and Van Zyl (2006) the “Red Book” AADD guideline under-estimates the AADD for smaller stand sizes (300 m^2 to 700 m^2 size range) and is too conservative for stand sizes larger than approximately 700 m^2.

In light of this, the deviation of the average potable water demand of the selected group of stands compared to the “Red Book” guideline will not be calculated. The results of this comparative analysis will therefore not be discussed any further. However, it nevertheless provides some indication as to the average water demand of stands with GAPs compared to this commonly used AADD guideline.

7.2 Jacobs *et al*. (2004)

The comparative analysis of the data versus the guideline of Jacobs *et al*. (2004) is similar to the method used with the “Hermanus pilot study”, where the guideline curve for “coastal winter rainfall regions” was applied for comparison. Although the mean AADD values provide a better comparison with the lower envelope of the guideline, as shown in Figure 6.4, the average reduction in water demand will be calculated based on the AADDs suggested by the main guideline curve for the selected groups of stands.

The difference between the mean AADD for each size class and the AADDs suggested by the guideline for corresponding stand sizes were calculated separately. The average reduction in AADD (based on measured use and that suggested by the guideline) for the entire stand size range was calculated by the “weighted average” method using the difference in the AADD of each size class.

The "weighted average" is similar to the arithmetic mean of the values in a sample, but instead of each value contributing equally to the final average, the proportional weight of each value is also taken into consideration. Each value contributes towards the weighted average based on its proportional weight (not value) in terms of the total sample size.

The average weighted "reduction" in AADD for the selected stand size range was calculated as shown in Table 6.5 below.

Table 6.5: Average weighted reduction in AADD based on Jacobs *et al*. (2004)

Stand size class (m^2)	**Number of records**	**Guideline AADD (l/stand/day)**	**Mean AADD (l/stand/day)**	**Difference in AADD (l/stand/day)**	**Difference in AADD (%)**
300	104	618.8	501.5	117.3	18.9
400	172	729.4	528.5	200.9	27.5
500	822	840.0	607.6	232.3	27.7
600	609	950.6	664.0	286.5	30.1
700	650	1 061.2	710.6	350.6	33.0
800	355	1 171.8	769.7	402.1	34.3
900	254	1 251.3	852.6	398.7	31.9
1 000	379	1 307.5	793.7	513.9	39.3
1 100	126	1 363.8	818.2	545.6	40.0
1 200	73	1 420.0	1 040.5	379.5	26.7
1 300	49	1 476.3	1 036.6	439.7	29.8
Total	**3 593**	**Average weighted reduction in AADD**		**333**	**31.4**

As a result, an average weighted "reduction" in the AADD of 333 l/stand/day was calculated across the selected stand size range (250 m^2 to 1 350 m^2), as shown in Table 6.5. This represents an average reduction of 31.4% in the AADD of the selected stands, based on the guidelines of Jacobs *et al*. (2004).

7.3 Van Zyl *et al*. (2008)

The comparison of the data with the AADD guideline presented by Van Zyl *et al*. (2008) is also similar to that used in the "Hermanus pilot study". Although the mean AADD values compare more favourably with the 5% confidence limit of the guideline, as shown in Figure 6.5, the main guideline curve will be used to calculate the average reduction in water demand for the groups of stands in the selected stand size range.

The difference between the mean AADD for each size class and the AADDs as given in the guideline for corresponding stand sizes were calculated separately. The average weighted "reduction" in AADD (based on measured use and that suggested by the guideline) for the entire stand size range was calculated as summarised in Table 6.6.

Table 6.6: Average weighted reduction in AADD based on Van Zyl *et al*. (2008)

Stand size class (m^2)	Number of records	Guideline AADD (l/stand/day)	Mean AADD (l/stand/day)	Difference in AADD (l/stand/day)	Difference in AADD (%)
300	104	1 087.7	501.5	586.1	53.9
400	172	1 184.7	528.5	656.2	55.4
500	822	1 265.8	607.6	658.2	52.0
600	609	1 336.3	664.0	672.3	50.3
700	650	1 398.9	710.6	688.3	49.2
800	355	1 455.5	769.7	685.8	47.1
900	254	1 507.3	852.6	654.7	43.4
1 000	379	1 555.2	793.7	761.5	49.0
1 100	126	1 599.9	818.2	781.6	48.9
1 200	73	1 641.7	1 040.5	601.2	36.6
1 300	49	1 681.2	1 036.6	644.7	38.3
Total	**3 593**	**Average weighted reduction in AADD**		**680**	**49.4**

An average weighted "reduction" of 680 l/stand/day or 49.4% in the AADD was calculated for the range of stand sizes between 250 m^2 and 1 350 m^2, based on the water demand guidelines of Van Zyl *et al*. (2008) as shown in Table 6.6 above.

7.4 Overview

This study confirms the reduced average potable water demand at the selected residential stands with GAPs in the Cape Peninsula. The results of the comparative analyses are now compared with previous studies on the impact of private groundwater use on potable water demand, although past research on this topic remains limited.

The majority of the studies traced during this research reported only on the incidence of residential stands with GAPs in the specific study areas and did not investigate the supposed impact of private groundwater use on potable water consumption as such. Those studies that do address this issue were based entirely on metered water consumption with the average water saving estimated using the difference between the metered water use at stands with and without GAPs. In contrast, the comparative analyses of this study compare the water consumption at residential stands with GAPs to recently published AADD guidelines, and not the actual water demand of other residential stands (without GAPs) in the study area.

Past research reports that the "Red Book" model is too conservative. The difference between the average potable water demand and that suggested by the "Red Book" guideline was therefore not calculated and this comparative analysis is not discussed any further.

The results of the comparative analysis with the guidelines of Jacobs *et al*. (2004) and Van Zyl *et al*. (2008) respectively are divergent only due to the difference between these two sets of guidelines. Table 6.5 presents an average reduction of 31.4% or 333 l/stand/day in the AADD of the selected stands. This agrees well with the study by Garlipp (1978), which reported an average saving of 28.1% or 422 l/stand/day effected on stands with GAPs in Pretoria.

The results shown in Table 6.6 confirm an average reduction in AADD of 49.4% or 680 l/stand/day, which is significantly higher than that calculated with Table 6.5. It does, however, compare more favourably with the findings of Garlipp (1978) for a selected group of stands in Rustenburg where a saving of 45.3% or 775 l/stand/day in the average annual water consumption of stands with GAPs was calculated.

The results contained in Table 6.5 are nearly 50% higher than those presented by Simpson (1990), which reported an average reduction in municipal water use of 21% or 220 l/stand/day for properties with GAPs, also in the Pretoria area. It must therefore be noted that the focus areas of the studies that these results are being compared with are situated in the northern parts of South Africa which is a summer rainfall region.

The studies of Lomberg *et al*. (1996) and Saayman and Adams (2001) that focus on Port Elizabeth and Cape Town respectively, do not report on the reduction in AADD or give any quantitative figures in this regard and could therefore not be used to compare with the results of the comparative analyses. The only past research work on this topic that covered Cape Town or the broader Cape Peninsula was presented by Maclear (1995). This study reported average reductions in summertime water consumption of between 60% and 80% at middle-income households with GAPs. The study only reports on summertime water demand of middle-income stands which, coupled with the fact that the number of stands that this study was based on is unknown, makes it unsuitable for an accurate comparison.

The separate studies by Garlipp (1978) and Simpson (1990) are therefore the only past research work that the results of this study could really be compared with. Although this work may be considered somewhat out-dated and less than ideal, as it focuses on areas in a summer rainfall region and not the Cape Peninsula, it remains particularly applicable to this study as it is based on a relatively large number of stands (similar to the sample size used for this study) and reports quantitative figures of average reductions in AADD at residential stands with GAPs.

8. Synopsis

8.1 Conclusion

The main objective of this study was to discuss and investigate the potable water demand of selected residential stands with access to groundwater in serviced areas of the Cape Peninsula and attempt to estimate the impact of private groundwater use. It is clear from the number of residential stands registered during the CCT's GAP registration process between 2000 and 2006 that the occurrence and use of private on-site GAPs is a popular feature in the Cape Peninsula, especially for outdoor purposes such as garden irrigation.

Based on the information and findings contained in this report, certain conclusions can be drawn directly from the results of the comparative analyses between the mean actual (measured) water demand of the selected stands with GAPs and recently published AADD guidelines as well as the comparison of these results with the findings of similar research work done in the past.

The water demand guideline of Jacobs *et al*. (2004) is considered the most favourable to draw conclusions from in this regard. The guideline curve for "coastal winter rainfall regions" as given in Jacobs *et al*. (2004) was used for the purposes of this study. This guideline was derived using measured water consumption from the CCT municipal treasury data base and is therefore better suited, with the focus area of this study being the Cape Peninsula.

The guideline presented by Van Zyl *et al*. (2008) was based on a single regression analysis of more than 1 million metered water consumption records extracted from various municipal treasury data bases across South Africa. This guideline, therefore, does not respect geographic location and was considered less appropriate to base a final conclusion on.

As mentioned in the discussion prior to this, the results of the comparative analysis with the guidelines of Jacobs *et al*. (2004) agree well with the findings of a similar study by Garlipp (1978) in Pretoria which confirmed a very comparable saving in potable water demand at stands with GAPs. They also compare well with the outcomes of Simpson (1990) which, although this study too focuses on Pretoria, is a more recent study that is based on a relatively large number of stands, similar to that used for this research.

The results of the comparative analysis therefore confirm the reduced potable water demand at residential stands with GAPs in the Cape Peninsula when compared to the water demand guidelines presented by Jacobs *et al*. (2004). Based on these results, the estimated saving in the average potable water demand at such stands nears a total of ± 10 kl/stand/month (or more than 30%) which is a significant water saving per household.

The results of this study are further supported by past research work, although previous studies on this topic are very limited. The outcome of this research does not contradict the findings of Garlipp (1978) and Simpson (1990) – instead it compares favourably with the findings of both these studies.

This study therefore confirms that residential properties with access to groundwater in serviced areas of the Cape Peninsula has a lower average metered water consumption from the municipal supply system, which is reflected as a reduction in potable water demand at such stands. Based on the assumptions made for the purposes of this study, the results are interpreted as an indication of the reduced water demand at residential stands where the private use of groundwater in addition to potable water is considered to be common.

8.2 Future research needs

The CCT resumed the GAP registration initiative in September 2011, and the logical extension of this research will therefore be to use this fresh data to investigate the water demand of these stands. The data can also be compared with the true water demand of stands without access to groundwater or where private groundwater use is considered not to be practised, rather than with AADD guidelines.

The development of this research can be expanded further to investigate the impact of private groundwater use on potable water demand in other areas of South Africa where the use of GAPs at residential stands is prevalent. Surveys and hydro-censuses similar to that referred to and used in this study can be launched in these areas as a means of gathering all the necessary information about such stands.

Another aspect of this research topic could be an investigation into the true water saving effected on stands where private GAPs are used, since the saving in potable water is potentially far less than the volume of groundwater it is replaced with. This would, however, require the identification of a group of residential stands with GAPs to participate in such a survey which would allow water meters to be fitted at the abstraction points to measure the actual volume of groundwater being used. The average reduction in the potable water demand of the selected stands can then be compared with the quantity of groundwater being used.

Lastly, the physical registration forms used with the previous process make interpretation difficult and can be misplaced easily - as was the case with the records of the previous registration process, which resulted in the difficulty experienced in obtaining them. If this valuable registration data is captured electronically or spatially from the onset, not only does this allow the immediate processing and easy duplication thereof, but it also prevents the extensive process of verification of the physical data captured long after the registration was concluded. It is unknown whether the information registered during the CCT’s latest GAP registration initiative is being captured electronically or converted to electronic format.

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